APPENDIX I

STATISTICAL TABLES AND PROCEDURES

I.1 Normal Distribution

Table I.1 Cumulative Normal Distribution Function Φ(z)

z	*0.00*	*0.01*	*0.02*	*0.03*	*0.04*	*0.05*	*0.06*	*0.07*	*0.08*	*0.09*
0.00	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.10	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5674	0.5714	0.5753
0.20	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.30	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.40	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.50	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.60	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.70	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.80	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.90	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.6315	0.8340	0.8365	0.8389
1.00	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.10	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.20	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.30	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.40	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.50	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.60	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.70	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.80	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.90	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.00	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.10	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.20	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.30	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.40	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.50	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.60	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.70	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.80	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.90	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.00	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.10	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.20	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.30	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.40	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

Negative values of z can be obtained from the relationship $\Phi(-z) = 1 - \Phi(z)$.

I.2 Sample Sizes for Statistical Tests

Table I.2a Sample Sizes for Sign Test
(Number of measurements to be performed in each survey unit)

	(α,β) or (β,α)														
Δ/σ	0.01 0.01	0.01 0.025	0.01 0.05	0.01 0.1	0.01 0.25	0.025 0.025	0.025 0.05	0.025 0.1	0.025 0.25	0.05 0.05	0.05 0.1	0.05 0.25	0.1 0.1	0.1 0.25	0.25 0.25
0.1	4095	3476	2984	2463	1704	2907	2459	1989	1313	2048	1620	1018	1244	725	345
0.2	1035	879	754	623	431	735	622	503	333	518	410	258	315	184	88
0.3	468	398	341	282	195	333	281	227	150	234	185	117	143	83	40
0.4	270	230	197	162	113	192	162	131	87	136	107	68	82	48	23
0.5	178	152	130	107	75	126	107	87	58	89	71	45	54	33	16
0.6	129	110	94	77	54	92	77	63	42	65	52	33	40	23	11
0.7	99	83	72	59	41	70	59	48	33	50	40	26	30	18	9
0.8	80	68	58	48	34	57	48	39	26	40	32	21	24	15	8
0.9	66	57	48	40	28	47	40	33	22	34	27	17	21	12	6
1.0	57	48	41	34	24	40	34	28	18	29	23	15	18	11	5
1.1	50	42	36	30	21	35	30	24	17	26	21	14	16	10	5
1.2	45	38	33	27	20	32	27	22	15	23	18	12	15	9	5
1.3	41	35	30	26	17	29	24	21	14	21	17	11	14	8	4
1.4	38	33	28	23	16	27	23	18	12	20	16	10	12	8	4
1.5	35	30	27	22	15	26	22	17	12	18	15	10	11	8	4
1.6	34	29	24	21	15	24	21	17	11	17	14	9	11	6	4
1.7	33	28	24	20	14	23	20	16	11	17	14	9	10	6	4
1.8	32	27	23	20	14	22	20	16	11	16	12	9	10	6	4
1.9	30	26	22	18	14	22	18	15	10	16	12	9	10	6	4
2.0	29	26	22	18	12	21	18	15	10	15	12	8	10	6	3
2.5	28	23	21	17	12	20	17	14	10	15	11	8	9	5	3
3.0	27	23	20	17	12	20	17	14	9	14	11	8	9	5	3

Table I.2b Sample Sizes for Wilcoxon Rank Sum Test

(Number of measurements to be performed in the reference area and in each survey unit)

	(α,β) or (β,α)														
Δ/σ	0.01 0.01	0.01 0.025	0.01 0.05	0.01 0.1	0.01 0.25	0.025 0.025	0.025 0.05	0.025 0.1	0.025 0.25	0.05 0.05	0.05 0.1	0.05 0.25	0.1 0.1	0.1 0.25	0.25 0.25
0.1	5452	4627	3972	3278	2268	3870	3273	2646	1748	2726	2157	1355	1655	964	459
0.2	1370	1163	998	824	570	973	823	665	440	685	542	341	416	243	116
0.3	614	521	448	370	256	436	369	298	197	307	243	153	187	109	52
0.4	350	297	255	211	146	248	210	170	112	175	139	87	106	62	30
0.5	227	193	166	137	95	162	137	111	73	114	90	57	69	41	20
0.6	161	137	117	97	67	114	97	78	52	81	64	40	49	29	14
0.7	121	103	88	73	51	86	73	59	39	61	48	30	37	22	11
0.8	95	81	69	57	40	68	57	46	31	48	38	24	29	17	8
0.9	77	66	56	47	32	55	46	38	25	39	31	20	24	14	7
1.0	64	55	47	39	27	46	39	32	21	32	26	16	20	12	6
1.1	55	47	40	33	23	39	33	27	18	28	22	14	17	10	5
1.2	48	41	35	29	20	34	29	24	16	24	19	12	15	9	4
1.3	43	36	31	26	18	30	26	21	14	22	17	11	13	8	4
1.4	38	32	28	23	16	27	23	19	13	19	15	10	12	7	4
1.5	35	30	25	21	15	25	21	17	11	18	14	9	11	7	3
1.6	32	27	23	19	14	23	19	16	11	16	13	8	10	6	3
1.7	30	25	22	18	13	21	18	15	10	15	12	8	9	6	3
1.8	28	24	20	17	12	20	17	14	9	14	11	7	9	5	3
1.9	26	22	19	16	11	19	16	13	9	13	11	7	8	5	3
2.0	25	21	18	15	11	18	15	12	8	13	10	7	8	5	3
2.25	22	19	16	14	10	16	14	11	8	11	9	6	7	4	2
2.5	21	18	15	13	9	15	13	10	7	11	9	6	7	4	2
2.75	20	17	15	12	9	14	12	10	7	10	8	5	6	4	2
3.0	19	16	14	12	8	14	12	10	6	10	8	5	6	4	2
3.5	18	16	13	11	8	13	11	9	6	9	8	5	6	4	2
4.0	18	15	13	11	8	13	11	9	6	9	7	5	6	4	2

I.3 Critical Values for the SignTest

Table I.3 Critical Values for the Sign Test Statistic S+

	Alpha								
N	***0.005***	***0.01***	***0.025***	***0.05***	***0.1***	***0.2***	***0.3***	***0.4***	***0.5***
4	4	4	4	4	3	3	3	2	2
5	5	5	5	4	4	3	3	3	2
6	6	6	5	5	5	4	4	3	3
7	7	6	6	6	5	5	4	4	3
8	7	7	7	6	6	5	5	4	4
9	8	8	7	7	6	6	5	5	4
10	9	9	8	8	7	6	6	5	5
11	10	9	9	8	8	7	6	6	5
12	10	10	9	9	8	7	7	6	6
13	11	11	10	9	9	8	7	7	6
14	12	11	11	10	9	9	8	7	7
15	12	12	11	11	10	9	9	8	7
16	13	13	12	11	11	10	9	9	8
17	14	13	12	12	11	10	10	9	8
18	14	14	13	12	12	11	10	10	9
19	15	14	14	13	12	11	11	10	9
20	16	15	14	14	13	12	11	11	10
21	16	16	15	14	13	12	12	11	10
22	17	16	16	15	14	13	12	12	11
23	18	17	16	15	15	14	13	12	11
24	18	18	17	16	15	14	13	13	12
25	19	18	17	17	16	15	14	13	12
26	19	19	18	17	16	15	14	14	13
27	20	19	19	18	17	16	15	14	13
28	21	20	19	18	17	16	15	15	14
29	21	21	20	19	18	17	16	15	14
30	22	21	20	19	19	17	16	16	15

Table I.3 Critical Values for the Sign Test Statistic S+ (continued)

	Alpha								
N	*0.005*	*0.01*	*0.025*	*0.05*	*0.1*	*0.2*	*0.3*	*0.4*	*0.5*
31	23	22	21	20	19	18	17	16	15
32	23	23	22	21	20	18	17	17	16
33	24	23	22	21	20	19	18	17	16
34	24	24	23	22	21	19	19	18	17
35	25	24	23	22	21	20	19	18	17
36	26	25	24	23	22	21	20	19	18
37	26	26	24	23	22	21	20	19	18
38	27	26	25	24	23	22	21	20	19
39	27	27	26	25	23	22	21	20	19
40	28	27	26	25	24	23	22	21	20
41	29	28	27	26	25	23	22	21	20
42	29	28	27	26	25	24	23	22	21
43	30	29	28	27	26	24	23	22	21
44	30	30	28	27	26	25	24	23	22
45	31	30	29	28	27	25	24	23	22
46	32	31	30	29	27	26	25	24	23
47	32	31	30	29	28	26	25	24	23
48	33	32	31	30	28	27	26	25	24
49	33	33	31	30	29	27	26	25	24
50	34	33	32	31	30	28	27	26	25

For N greater than 50, the table (critical) value can be calculated from:

$$\frac{N}{2} + \frac{z}{2}\sqrt{N}$$

z is the (1-α) percentile of a standard normal distribution, which can be found on page I-10 or on page 5-28 in Table 5.2.

I.4 Critical Values for the WRS Test

Table I.4 Critical Values for the WRS test

m is the number of reference area samples and n is the number of survey unit samples.

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 2	α=0.001	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43
	α=0.005	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	40	42
	α=0.01	7	9	11	13	15	17	19	21	23	25	27	28	30	32	34	36	38	39	41
	α=0.025	7	9	11	13	15	17	18	20	22	23	25	27	29	31	33	34	36	38	40
	α=0.05	7	9	11	12	14	16	17	19	21	23	24	26	27	29	31	33	34	36	38
	α=0.1	7	8	10	11	13	15	16	18	19	21	22	24	26	27	29	30	32	33	35

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 3	α=0.001	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	56	59	62	65
	α=0.005	12	15	18	21	24	27	30	32	35	38	40	43	46	48	51	54	57	59	62
	α=0.01	12	15	18	21	24	26	29	31	34	37	39	42	45	47	50	52	55	58	60
	α=0.025	12	15	18	20	22	25	27	30	32	35	37	40	42	45	47	50	52	55	57
	α=0.05	12	14	17	19	21	24	26	28	31	33	36	38	40	43	45	47	50	52	54
	α=0.1	11	13	16	18	20	22	24	27	29	31	33	35	37	40	42	44	46	48	50

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 4	α=0.001	18	22	26	30	34	38	42	46	49	53	57	60	64	68	71	75	78	82	86
	α=0.005	18	22	26	30	33	37	40	44	47	51	54	58	61	64	68	71	75	78	81
	α=0.01	18	22	26	29	32	36	39	42	46	49	52	56	59	62	66	69	72	76	79
	α=0.025	18	22	25	28	31	34	37	41	44	47	50	53	56	59	62	66	69	72	75
	α=0.05	18	21	24	27	30	33	36	39	42	45	48	51	54	57	59	62	65	68	71
	α=0.1	17	20	22	25	28	31	34	36	39	42	45	48	50	53	56	59	61	64	67

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 5	α=0.001	25	30	35	40	45	50	54	58	63	67	72	76	81	85	89	94	98	102	107
	α=0.005	25	30	35	39	43	48	52	56	60	64	68	72	77	81	85	89	93	97	101
	α=0.01	25	30	34	38	42	46	50	54	58	62	66	70	74	78	82	86	90	94	98
	α=0.025	25	29	33	37	41	44	48	52	56	60	63	67	71	75	79	82	86	90	94
	α=0.05	24	28	32	35	39	43	46	50	53	57	61	64	68	71	75	79	82	86	89
	α=0.1	23	27	30	34	37	41	44	47	51	54	57	61	64	67	71	74	77	81	84

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 6	α=0.001	33	39	45	51	57	63	67	72	77	82	88	93	98	103	108	113	118	123	128
	α=0.005	33	39	44	49	54	59	64	69	74	79	83	88	93	98	103	107	112	117	122
	α=0.01	33	39	43	48	53	58	62	67	72	77	81	86	91	95	100	104	109	114	118
	α=0.025	33	37	42	47	51	56	60	64	69	73	78	82	87	91	95	100	104	109	113
	α=0.05	32	36	41	45	49	54	58	62	66	70	75	79	83	87	91	96	100	104	108
	α=0.1	31	35	39	43	47	51	55	59	63	67	71	75	79	83	87	91	94	98	102

Table I.4 Critical Values for the WRS Test (continued)

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 7	α=0.001	42	49	56	63	69	75	81	87	92	98	104	110	116	122	128	133	139	145	151
	α=0.005	42	49	55	61	66	72	77	83	88	94	99	105	110	116	121	127	132	138	143
	α=0.01	42	48	54	59	65	70	76	81	86	92	97	102	108	113	118	123	129	134	139
	α=0.025	42	47	52	57	63	68	73	78	83	88	93	98	103	108	113	118	123	128	133
	α=0.05	41	46	51	56	61	65	70	75	80	85	90	94	99	104	109	113	118	123	128
	α=0.1	40	44	49	54	58	63	67	72	76	81	85	90	94	99	103	108	112	117	121

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 8	α=0.001	52	60	68	75	82	89	95	102	109	115	122	128	135	141	148	154	161	167	174
	α=0.005	52	60	66	73	79	85	92	98	104	110	116	122	129	135	141	147	153	159	165
	α=0.01	52	59	65	71	77	84	90	96	102	108	114	120	125	131	137	143	149	155	161
	α=0.025	51	57	63	69	75	81	86	92	98	104	109	115	121	126	132	137	143	149	154
	α=0.05	50	56	62	67	73	78	84	89	95	100	105	111	116	122	127	132	138	143	148
	α=0.1	49	54	60	65	70	75	80	85	91	96	101	106	111	116	121	126	131	136	141

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 9	α=0.001	63	72	81	88	96	104	111	118	126	133	140	147	155	162	169	176	183	190	198
	α=0.005	63	71	79	86	93	100	107	114	121	127	134	141	148	155	161	168	175	182	188
	α=0.01	63	70	77	84	91	98	105	111	118	125	131	138	144	151	157	164	170	177	184
	α=0.025	62	69	76	82	88	95	101	108	114	120	126	133	139	145	151	158	164	170	176
	α=0.05	61	67	74	80	86	92	98	104	110	116	122	128	134	140	146	152	158	164	170
	α=0.1	60	66	71	77	83	89	94	100	106	112	117	123	129	134	140	145	151	157	162

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 10	α=0.001	75	85	94	103	111	119	128	136	144	152	160	167	175	183	191	199	207	215	222
	α=0.005	75	84	92	100	108	115	123	131	138	146	153	160	168	175	183	190	197	205	212
	α=0.01	75	83	91	98	106	113	121	128	135	142	150	157	164	171	178	186	193	200	207
	α=0.025	74	81	89	96	103	110	117	124	131	138	145	151	158	165	172	179	186	192	199
	α=0.05	73	80	87	93	100	107	114	120	127	133	140	147	153	160	166	173	179	186	192
	α=0.1	71	78	84	91	97	103	110	116	122	128	135	141	147	153	160	166	172	178	184

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 11	α=0.001	88	99	109	118	127	136	145	154	163	171	180	188	197	206	214	223	231	240	248
	α=0.005	88	98	107	115	124	132	140	148	157	165	173	181	189	197	205	213	221	229	237
	α=0.01	88	97	105	113	122	130	138	146	153	161	169	177	185	193	200	208	216	224	232
	α=0.025	87	95	103	111	118	126	134	141	149	156	164	171	179	186	194	201	208	216	223
	α=0.05	86	93	101	108	115	123	130	137	144	152	159	166	173	180	187	195	202	209	216
	α=0.1	84	91	98	105	112	119	126	133	139	146	153	160	167	173	180	187	194	201	207

Table I.4 Critical Values for the WRS Test (continued)

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 12	α=0.001	102	114	125	135	145	154	164	173	183	192	202	210	220	230	238	247	256	266	275
	α=0.005	102	112	122	131	140	149	158	167	176	185	194	202	211	220	228	237	246	254	263
	α=0.01	102	111	120	129	138	147	156	164	173	181	190	198	207	215	223	232	240	249	257
	α=0.025	100	109	118	126	135	143	151	159	168	176	184	192	200	208	216	224	232	240	248
	α=0.05	99	108	116	124	132	140	147	155	165	171	179	186	194	202	209	217	225	233	240
	α=0.1	97	105	113	120	128	135	143	150	158	165	172	180	187	194	202	209	216	224	231

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 13	α=0.001	117	130	141	152	163	173	183	193	203	213	223	233	243	253	263	273	282	292	302
	α=0.005	117	128	139	148	158	168	177	187	196	206	215	225	234	243	253	262	271	280	290
	α=0.01	116	127	137	146	156	165	174	184	193	202	211	220	229	238	247	256	265	274	283
	α=0.025	115	125	134	143	152	161	170	179	187	196	205	214	222	231	239	248	257	265	274
	α=0.05	114	123	132	140	149	157	166	174	183	191	199	208	216	224	233	241	249	257	266
	α=0.1	112	120	129	137	145	153	161	169	177	185	193	201	209	217	224	232	240	248	256

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 14	α=0.001	133	147	159	171	182	193	204	215	225	236	247	257	268	278	289	299	310	320	330
	α=0.005	133	145	156	167	177	187	198	208	218	228	238	248	258	268	278	288	298	307	317
	α=0.01	132	144	154	164	175	185	194	204	214	224	234	243	253	263	272	282	291	301	311
	α=0.025	131	141	151	161	171	180	190	199	208	218	227	236	245	255	264	273	282	292	301
	α=0.05	129	139	149	158	167	176	185	194	203	212	221	230	239	248	257	265	274	283	292
	α=0.1	128	136	145	154	163	171	180	189	197	206	214	223	231	240	248	257	265	273	282

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 15	α=0.001	150	165	178	190	202	212	225	237	248	260	271	282	293	304	316	327	338	349	360
	α=0.005	150	162	174	186	197	208	219	230	240	251	262	272	283	293	304	314	325	335	346
	α=0.01	149	161	172	183	194	205	215	226	236	247	257	267	278	288	298	308	319	329	339
	α=0.025	148	159	169	180	190	200	210	220	230	240	250	260	270	280	289	299	309	319	329
	α=0.05	146	157	167	176	186	196	206	215	225	234	244	253	263	272	282	291	301	310	319
	α=0.1	144	154	163	172	182	191	200	209	218	227	236	246	255	264	273	282	291	300	309

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 16	α=0.001	168	184	197	210	223	236	248	260	272	284	296	308	320	332	343	355	367	379	390
	α=0.005	168	181	194	206	218	229	241	252	264	275	286	298	309	320	331	342	353	365	376
	α=0.01	167	180	192	203	215	226	237	248	259	270	281	292	303	314	325	336	347	357	368
	α=0.025	166	177	188	200	210	221	232	242	253	264	274	284	295	305	316	326	337	347	357
	α=0.05	164	175	185	196	206	217	227	237	247	257	267	278	288	298	308	318	328	338	348
	α=0.1	162	172	182	192	202	211	221	231	241	250	260	269	279	289	298	308	317	327	336

Table I.4 Critical Values for the WRS Test (continued)

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 17	α=0.001	187	203	218	232	245	258	271	284	297	310	322	335	347	360	372	384	397	409	422
	α=0.005	187	201	214	227	239	252	264	276	288	300	312	324	336	347	359	371	383	394	406
	α=0.01	186	199	212	224	236	248	260	272	284	295	307	318	330	341	353	364	376	387	399
	α=0.025	184	197	209	220	232	243	254	266	277	288	299	310	321	332	343	354	365	376	387
	α=0.05	183	194	205	217	228	238	249	260	271	282	292	303	313	324	335	345	356	366	377
	α=0.1	180	191	202	212	223	233	243	253	264	274	284	294	305	315	325	335	345	355	365

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 18	α=0.001	207	224	239	254	268	282	296	309	323	336	349	362	376	389	402	415	428	441	454
	α=0.005	207	222	236	249	262	275	288	301	313	326	339	351	364	376	388	401	413	425	438
	α=0.01	206	220	233	246	259	272	284	296	309	321	333	345	357	370	382	394	406	418	430
	α=0.025	204	217	230	242	254	266	278	290	302	313	325	337	348	360	372	383	395	406	418
	α=0.05	202	215	226	238	250	261	273	284	295	307	318	329	340	352	363	374	385	396	407
	α=0.1	200	211	222	233	244	255	266	277	288	299	309	320	331	342	352	363	374	384	395

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 19	α=0.001	228	246	262	277	292	307	321	335	350	364	377	391	405	419	433	446	460	473	487
	α=0.005	227	243	258	272	286	300	313	327	340	353	366	379	392	405	419	431	444	457	470
	α=0.01	226	242	256	269	283	296	309	322	335	348	361	373	386	399	411	424	437	449	462
	α=0.025	225	239	252	265	278	290	303	315	327	340	352	364	377	389	401	413	425	437	450
	α=0.05	223	236	248	261	273	285	297	309	321	333	345	356	368	380	392	403	415	427	439
	α=0.1	220	232	244	256	267	279	290	302	313	325	336	347	358	370	381	392	403	415	426

	n =	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
m = 20	α=0.001	250	269	286	302	317	333	348	363	377	392	407	421	435	450	464	479	493	507	521
	α=0.005	249	266	281	296	311	325	339	353	367	381	395	409	422	436	450	463	477	490	504
	α=0.01	248	264	279	293	307	321	335	349	362	376	389	402	416	429	442	456	469	482	495
	α=0.025	247	261	275	289	302	315	329	341	354	367	380	393	406	419	431	444	457	470	482
	α=0.05	245	258	271	284	297	310	322	335	347	360	372	385	397	409	422	434	446	459	471
	α=0.1	242	254	267	279	291	303	315	327	339	351	363	375	387	399	410	422	434	446	458

Reject the null hypothesis if the test statistic (W_r) is greater than the table (critical) value. For n or m greater than 20, the table (critical) value can be calculated from:

$$m(n+m+1)/2 + z\sqrt{nm(n+m+1)/12} \quad \text{(I.1)}$$

if there are few or no ties, and from

$$m(n+m+1)/2 + z\sqrt{\frac{nm}{12}[(n+m+1) - \sum_{j=1}^{g} \frac{t_j(t_j^2-1)}{(n+m)(n+m-1)}]} \quad \text{(I.2)}$$

if there are many ties, where g is the number of groups of tied measurements and t_j is the number of tied measurements in the jth group. z is the $(1-\alpha)$ percentile of a standard normal distribution, which can be found in the following table:

α	z
0.001	3.09
0.005	2.575
0.01	2.326
0.025	1.960
0.05	1.645
0.1	1.282

Other values can be found in Table I-1.

I.5 Probability of Detecting an Elevated Area

Table I.5 Risk that an Elevated Area with Length L/G and Shape S will not be Detected and the Area (%) of the Elevated Area Relative to a Triangular Sample Grid Area of 0.866 G^2

	Shape Parameter, S																			
	0.10		0.20		0.30		0.40		0.50		0.60		0.70		0.80		0.90		1.00	
L/G	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area
0.01	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%
0.02	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%
0.03	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%
0.04	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	0.99	1%	0.99	1%
0.05	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	1.00	<1%	0.99	1%	0.99	1%	0.99	1%	0.99	1%	0.99	1%
0.06	1.00	<1%	1.00	<1%	1.00	<1%	0.99	<1%	0.99	1%	0.99	1%	0.99	1%	0.99	1%	0.99	1%	0.99	1%
0.07	1.00	<1%	1.00	<1%	0.99	1%	0.99	<1%	0.99	1%	0.99	1%	0.99	1%	0.99	1%	0.98	2%	0.98	2%
0.08	1.00	<1%	1.00	<1%	0.99	1%	0.99	<1%	0.99	1%	0.99	1%	0.98	2%	0.98	2%	0.98	2%	0.98	2%
0.09	1.00	<1%	0.99	1%	0.99	1%	0.99	1%	0.99	1%	0.98	2%	0.98	2%	0.98	2%	0.97	3%	0.97	3%
0.10	1.00	<1%	0.99	1%	0.99	1%	0.99	1%	0.98	2%	0.98	2%	0.97	3%	0.97	3%	0.97	3%	0.96	4%
0.11	1.00	<1%	0.99	1%	0.99	1%	0.98	2%	0.98	2%	0.97	3%	0.97	3%	0.96	4%	0.96	4%	0.96	4%
0.12	0.99	1%	0.99	1%	0.98	2%	0.98	2%	0.97	3%	0.97	3%	0.96	4%	0.96	4%	0.95	5%	0.95	5%
0.13	0.99	1%	0.99	1%	0.98	2%	0.98	2%	0.97	3%	0.96	4%	0.96	4%	0.95	5%	0.94	6%	0.94	6%
0.14	0.99	1%	0.99	1%	0.98	2%	0.97	3%	0.96	4%	0.96	4%	0.95	5%	0.94	6%	0.94	6%	0.93	7%
0.15	0.99	1%	0.98	2%	0.98	2%	0.97	3%	0.96	4%	0.95	5%	0.94	6%	0.93	7%	0.93	7%	0.92	8%
0.16	0.99	1%	0.98	2%	0.97	3%	0.96	4%	0.95	5%	0.94	6%	0.94	7%	0.93	7%	0.92	8%	0.91	9%
0.17	0.99	1%	0.98	2%	0.97	3%	0.96	4%	0.95	5%	0.94	6%	0.93	7%	0.92	8%	0.91	9%	0.90	10%
0.18	0.99	1%	0.98	2%	0.96	4%	0.95	5%	0.94	6%	0.93	7%	0.92	8%	0.91	9%	0.89	11%	0.88	12%
0.19	0.99	1%	0.97	3%	0.96	4%	0.95	5%	0.93	7%	0.92	8%	0.91	9%	0.90	10%	0.88	12%	0.87	13%
0.20	0.99	1%	0.97	3%	0.96	4%	0.94	6%	0.93	7%	0.91	9%	0.90	10%	0.88	12%	0.87	13%	0.85	15%
0.21	0.98	2%	0.97	3%	0.95	5%	0.94	6%	0.92	8%	0.90	10%	0.89	11%	0.87	13%	0.86	14%	0.84	16%
0.22	0.98	2%	0.96	4%	0.95	5%	0.93	7%	0.91	9%	0.89	11%	0.88	12%	0.86	14%	0.84	16%	0.82	18%
0.23	0.98	2%	0.96	4%	0.94	6%	0.92	8%	0.90	10%	0.88	12%	0.87	13%	0.85	15%	0.83	17%	0.81	19%
0.24	0.98	2%	0.96	4%	0.94	6%	0.92	8%	0.90	10%	0.87	13%	0.85	15%	0.83	17%	0.81	19%	0.79	21%
0.25	0.98	2%	0.95	5%	0.93	7%	0.91	9%	0.89	11%	0.86	14%	0.84	16%	0.82	18%	0.80	20%	0.77	23%
0.26	0.98	2%	0.95	5%	0.93	7%	0.90	10%	0.88	12%	0.85	15%	0.83	17%	0.80	20%	0.78	22%	0.75	25%
0.27	0.97	3%	0.95	5%	0.92	8%	0.89	11%	0.87	13%	0.84	16%	0.81	19%	0.79	21%	0.76	24%	0.74	26%
0.28	0.97	3%	0.94	6%	0.91	9%	0.89	11%	0.86	14%	0.83	17%	0.80	20%	0.77	23%	0.74	26%	0.72	28%
0.29	0.97	3%	0.94	6%	0.91	9%	0.88	12%	0.85	15%	0.82	18%	0.79	21%	0.76	24%	0.73	27%	0.69	31%
0.30	0.97	3%	0.93	7%	0.90	10%	0.87	13%	0.84	16%	0.80	20%	0.77	23%	0.74	26%	0.71	29%	0.67	33%

Guidance for using Table I.5 can be found in Gilbert 1987 and EPA 1989a.

Table I.5 Risk that an Elevated Area with Length L/G and Shape S will not be Detected and the Area (%) of the Elevated Area Relative to a Triangular Sample Grid Area of 0.866 G^2 (continued)

	Shape Parameter, S																			
	0.10		0.20		0.30		0.40		0.50		0.60		0.70		0.80		0.90		1.00	
L/G	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area
0.31	0.97	3%	0.93	7%	0.90	10%	0.86	14%	0.83	17%	0.79	21%	0.76	24%	0.72	28%	0.69	31%	0.65	35%
0.32	0.96	4%	0.93	7%	0.89	11%	0.85	15%	0.81	19%	0.78	22%	0.74	26%	0.70	30%	0.67	33%	0.63	37%
0.33	0.96	4%	0.92	8%	0.88	12%	0.84	16%	0.80	20%	0.76	24%	0.72	28%	0.68	32%	0.64	36%	0.61	40%
0.34	0.96	4%	0.92	8%	0.87	13%	0.83	17%	0.79	21%	0.75	25%	0.71	29%	0.66	34%	0.62	38%	0.58	42%
0.35	0.96	4%	0.91	9%	0.87	13%	0.82	18%	0.78	22%	0.73	27%	0.69	31%	0.64	36%	0.60	40%	0.56	44%
0.36	0.95	5%	0.91	9%	0.86	14%	0.81	19%	0.76	24%	0.72	28%	0.67	33%	0.62	38%	0.58	42%	0.53	47%
0.37	0.95	5%	0.90	10%	0.85	15%	0.80	20%	0.75	25%	0.70	30%	0.65	35%	0.60	40%	0.55	45%	0.50	50%
0.38	0.95	5%	0.90	10%	0.84	16%	0.79	21%	0.74	26%	0.69	31%	0.63	37%	0.58	42%	0.53	47%	0.48	52%
0.39	0.94	6%	0.89	11%	0.83	17%	0.78	22%	0.72	28%	0.67	33%	0.61	39%	0.56	44%	0.50	50%	0.45	55%
0.40	0.94	6%	0.88	12%	0.83	17%	0.77	23%	0.71	29%	0.65	35%	0.59	41%	0.54	46%	0.48	52%	0.42	58%
0.41	0.94	6%	0.88	12%	0.82	18%	0.76	24%	0.70	30%	0.63	37%	0.57	43%	0.51	49%	0.45	55%	0.39	61%
0.42	0.94	6%	0.87	13%	0.81	19%	0.74	26%	0.68	32%	0.62	38%	0.55	45%	0.49	51%	0.42	58%	0.36	64%
0.43	0.93	7%	0.87	13%	0.80	20%	0.73	27%	0.66	34%	0.60	40%	0.53	47%	0.46	54%	0.40	60%	0.33	67%
0.44	0.93	7%	0.86	14%	0.79	21%	0.72	28%	0.65	35%	0.58	42%	0.51	49%	0.44	56%	0.37	63%	0.30	70%
0.45	0.93	7%	0.85	15%	0.78	22%	0.71	29%	0.63	37%	0.56	44%	0.49	51%	0.41	59%	0.34	66%	0.27	73%
0.46	0.92	8%	0.85	15%	0.77	23%	0.69	31%	0.62	38%	0.54	46%	0.46	54%	0.39	61%	0.31	69%	0.23	77%
0.47	0.92	8%	0.84	16%	0.76	24%	0.68	32%	0.60	40%	0.52	48%	0.44	56%	0.36	64%	0.28	72%	0.20	80%
0.48	0.92	8%	0.83	17%	0.75	25%	0.67	33%	0.58	42%	0.50	50%	0.41	59%	0.33	67%	0.25	75%	0.16	84%
0.49	0.91	9%	0.83	17%	0.74	26%	0.65	35%	0.56	44%	0.48	52%	0.39	61%	0.30	70%	0.22	78%	0.13	87%
0.50	0.91	9%	0.82	18%	0.73	27%	0.64	36%	0.55	45%	0.46	54%	0.37	63%	0.27	73%	0.18	82%	0.09	91%
0.51	0.91	9%	0.81	19%	0.72	28%	0.62	38%	0.53	47%	0.43	57%	0.34	66%	0.25	75%	0.15	85%	0.07	94%
0.52	0.90	10%	0.80	20%	0.71	29%	0.61	39%	0.51	49%	0.41	59%	0.32	69%	0.22	78%	0.13	88%	0.05	98%
0.53	0.90	10%	0.80	20%	0.70	31%	0.59	41%	0.49	51%	0.39	61%	0.29	71%	0.19	82%	0.10	92%	0.03	102%
0.54	0.89	11%	0.79	21%	0.68	32%	0.58	42%	0.47	53%	0.37	63%	0.27	74%	0.17	85%	0.08	95%	0.02	106%
0.55	0.89	11%	0.78	22%	0.67	33%	0.56	44%	0.46	55%	0.35	66%	0.24	77%	0.14	88%	0.06	99%	0.01	110%
0.56	0.89	11%	0.77	23%	0.66	34%	0.55	46%	0.44	57%	0.33	68%	0.22	80%	0.12	91%	0.04	102%	0.00	114%
0.57	0.88	12%	0.77	24%	0.65	35%	0.54	47%	0.42	59%	0.31	71%	0.20	83%	0.10	94%	0.02	106%	0.00	118%
0.58	0.88	12%	0.76	24%	0.64	37%	0.52	49%	0.40	61%	0.29	73%	0.18	85%	0.08	98%	0.01	110%	0.00	122%
0.59	0.87	13%	0.75	25%	0.63	38%	0.51	51%	0.39	63%	0.27	76%	0.16	88%	0.06	101%	0.00	114%	0.00	126%
0.60	0.87	13%	0.74	26%	0.62	39%	0.49	52%	0.37	65%	0.25	78%	0.14	91%	0.04	104%	0.00	118%	0.00	131%
0.61	0.87	13%	0.73	27%	0.60	40%	0.48	54%	0.35	67%	0.23	81%	0.12	94%	0.03	108%	0.00	121%	0.00	135%
0.62	0.86	14%	0.73	28%	0.59	42%	0.46	56%	0.34	70%	0.21	84%	0.10	98%	0.02	112%	0.00	126%	0.00	139%
0.63	0.86	14%	0.72	29%	0.58	43%	0.45	58%	0.32	72%	0.20	86%	0.09	101%	0.01	115%	0.00	130%	0.00	144%
0.64	0.85	15%	0.71	30%	0.57	45%	0.43	59%	0.30	74%	0.18	89%	0.07	104%	0.00	119%	0.00	134%	0.00	149%
0.65	0.85	15%	0.70	31%	0.56	46%	0.42	61%	0.29	77%	0.16	92%	0.06	107%	0.00	123%	0.00	138%	0.00	153%

Table I.5 Risk that an Elevated Area with Length L/G and Shape S will not be Detected and the Area (%) of the Elevated Area Relative to a Triangular Sample Grid Area of $0.866G^2$ (continued)

	Shape Parameter, S																			
	0.10		0.20		0.30		0.40		0.50		0.60		0.70		0.80		0.90		1.00	
L/G	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area	Risk	Area
0.66	0.84	16%	0.69	32%	0.55	47%	0.40	63%	0.27	79%	0.15	95%	0.05	111%	0.00	126%	0.00	142%	0.00	158%
0.67	0.84	16%	0.68	33%	0.53	49%	0.39	65%	0.25	81%	0.13	98%	0.03	114%	0.00	130%	0.00	147%	0.00	163%
0.68	0.84	17%	0.68	34%	0.52	50%	0.38	67%	0.24	84%	0.12	101%	0.02	117%	0.00	134%	0.00	151%	0.00	168%
0.69	0.83	17%	0.67	35%	0.51	52%	0.36	69%	0.22	86%	0.10	104%	0.01	121%	0.00	138%	0.00	155%	0.00	173%
0.70	0.83	18%	0.66	36%	0.50	53%	0.35	71%	0.21	89%	0.09	107%	0.01	124%	0.00	142%	0.00	160%	0.00	178%
0.71	0.82	18%	0.65	37%	0.49	55%	0.33	73%	0.20	91%	0.08	110%	0.00	128%	0.00	146%	0.00	165%	0.00	183%
0.72	0.82	19%	0.64	38%	0.48	56%	0.32	75%	0.18	94%	0.07	113%	0.00	132%	0.00	150%	0.00	169%	0.00	188%
0.73	0.81	19%	0.63	39%	0.46	58%	0.31	77%	0.17	97%	0.05	116%	0.00	135%	0.00	155%	0.00	174%	0.00	193%
0.74	0.81	20%	0.62	40%	0.45	60%	0.29	79%	0.15	99%	0.04	119%	0.00	139%	0.00	159%	0.00	179%	0.00	199%
0.75	0.80	20%	0.61	41%	0.44	61%	0.28	82%	0.14	102%	0.04	122%	0.00	143%	0.00	163%	0.00	184%	0.00	204%
0.76	0.80	21%	0.61	42%	0.43	63%	0.27	84%	0.13	105%	0.03	126%	0.00	147%	0.00	168%	0.00	189%	0.00	210%
0.77	0.79	22%	0.60	43%	0.42	65%	0.25	86%	0.12	108%	0.02	129%	0.00	151%	0.00	172%	0.00	194%	0.00	215%
0.78	0.79	22%	0.59	44%	0.40	66%	0.24	88%	0.10	110%	0.01	132%	0.00	154%	0.00	177%	0.00	199%	0.00	221%
0.79	0.78	23%	0.58	45%	0.39	68%	0.23	91%	0.09	113%	0.01	136%	0.00	158%	0.00	181%	0.00	204%	0.00	226%
0.80	0.78	23%	0.57	46%	0.38	70%	0.22	93%	0.08	116%	0.00	139%	0.00	163%	0.00	186%	0.00	209%	0.00	232%
0.81	0.77	24%	0.56	48%	0.37	71%	0.20	95%	0.07	119%	0.00	143%	0.00	167%	0.00	190%	0.00	214%	0.00	238%
0.82	0.77	24%	0.55	49%	0.36	73%	0.19	98%	0.06	122%	0.00	146%	0.00	171%	0.00	195%	0.00	220%	0.00	244%
0.83	0.76	25%	0.54	50%	0.35	75%	0.18	100%	0.05	125%	0.00	150%	0.00	175%	0.00	200%	0.00	225%	0.00	250%
0.84	0.76	26%	0.53	51%	0.33	77%	0.17	102%	0.05	128%	0.00	154%	0.00	179%	0.00	205%	0.00	230%	0.00	256%
0.85	0.75	26%	0.52	52%	0.32	79%	0.16	105%	0.04	131%	0.00	157%	0.00	183%	0.00	210%	0.00	236%	0.00	262%
0.86	0.74	27%	0.51	54%	0.31	80%	0.14	107%	0.03	134%	0.00	161%	0.00	188%	0.00	215%	0.00	241%	0.00	268%
0.87	0.74	27%	0.50	55%	0.30	82%	0.13	110%	0.02	137%	0.00	165%	0.00	192%	0.00	220%	0.00	247%	0.00	275%
0.88	0.73	28%	0.50	56%	0.29	84%	0.12	112%	0.02	140%	0.00	169%	0.00	197%	0.00	225%	0.00	253%	0.00	281%
0.89	0.73	29%	0.49	57%	0.28	86%	0.11	115%	0.01	144%	0.00	172%	0.00	201%	0.00	230%	0.00	259%	0.00	287%
0.90	0.72	29%	0.48	59%	0.27	88%	0.10	118%	0.01	147%	0.00	176%	0.00	206%	0.00	235%	0.00	264%	0.00	294%
0.91	0.72	30%	0.47	60%	0.26	90%	0.10	120%	0.01	150%	0.00	180%	0.00	210%	0.00	240%	0.00	270%	0.00	300%
0.92	0.71	31%	0.46	61%	0.25	92%	0.09	123%	0.00	154%	0.00	184%	0.00	215%	0.00	246%	0.00	276%	0.00	307%
0.93	0.71	31%	0.45	63%	0.24	94%	0.08	126%	0.00	157%	0.00	188%	0.00	220%	0.00	251%	0.00	282%	0.00	314%
0.94	0.70	32%	0.44	64%	0.23	96%	0.07	128%	0.00	160%	0.00	192%	0.00	224%	0.00	256%	0.00	288%	0.00	321%
0.95	0.69	33%	0.43	65%	0.22	98%	0.07	131%	0.00	164%	0.00	196%	0.00	229%	0.00	262%	0.00	295%	0.00	327%
0.96	0.69	33%	0.42	67%	0.21	100%	0.06	134%	0.00	167%	0.00	201%	0.00	234%	0.00	267%	0.00	301%	0.00	334%
0.97	0.68	34%	0.41	68%	0.20	102%	0.05	137%	0.00	171%	0.00	205%	0.00	239%	0.00	273%	0.00	307%	0.00	341%
0.98	0.68	35%	0.40	70%	0.19	105%	0.05	139%	0.00	174%	0.00	209%	0.00	244%	0.00	279%	0.00	314%	0.00	348%
0.99	0.67	36%	0.40	71%	0.18	107%	0.04	142%	0.00	178%	0.00	213%	0.00	249%	0.00	284%	0.00	320%	0.00	356%
1.00	0.67	36%	0.39	73%	0.17	109%	0.04	145%	0.00	181%	0.00	218%	0.00	254%	0.00	290%	0.00	326%	0.00	363%

I.6 Random Numbers

Table I.6 1,000 Random Numbers Uniformly Distributed between Zero and One

0.163601	0.647423	0.555548	0.248859	0.259801	0.718368	0.305020	0.812482	0.601951	0.973160
0.934196	0.951102	0.979831	0.132364	0.157808	0.040605	0.997626	0.896462	0.360578	0.443218
0.054552	0.965257	0.999181	0.172627	0.583713	0.852958	0.116336	0.748483	0.058602	0.738495
0.972409	0.241889	0.799991	0.926726	0.585505	0.453993	0.877990	0.947022	0.910821	0.388081
0.556401	0.621126	0.293328	0.984335	0.366531	0.912588	0.733824	0.092405	0.717362	0.423421
0.625153	0.838711	0.196153	0.630553	0.867808	0.957094	0.830218	0.783518	0.141557	0.444997
0.527330	0.124034	0.351792	0.161947	0.688925	0.140346	0.553577	0.890058	0.470457	0.566196
0.826643	0.673286	0.550827	0.885295	0.690781	0.371540	0.108632	0.090765	0.618443	0.937184
0.296068	0.891272	0.392367	0.649633	0.261410	0.523221	0.769081	0.358794	0.924341	0.167665
0.848882	0.083603	0.274621	0.268003	0.272254	0.017727	0.309463	0.445986	0.244653	0.944564
0.779276	0.484461	0.101393	0.995100	0.085164	0.611426	0.030270	0.494982	0.426236	0.270225
0.095038	0.577943	0.186239	0.267852	0.786070	0.208937	0.184565	0.826397	0.256825	0.489034
0.011672	0.844846	0.443407	0.915087	0.275906	0.883009	0.243728	0.865552	0.796671	0.314429
0.215993	0.476035	0.354717	0.883172	0.840666	0.393867	0.374810	0.222167	0.114691	0.596046
0.982374	0.101973	0.683995	0.730612	0.548200	0.084302	0.145212	0.337680	0.566173	0.592776
0.860868	0.794380	0.819422	0.752871	0.158956	0.317468	0.062387	0.909843	0.779089	0.648967
0.718917	0.696798	0.463655	0.762408	0.823097	0.843209	0.368678	0.996266	0.542048	0.663842
0.800735	0.225556	0.398048	0.437067	0.642698	0.144068	0.104212	0.675095	0.318953	0.648478
0.915538	0.711742	0.232159	0.242961	0.327863	0.156608	0.260175	0.385141	0.681475	0.978186
0.975506	0.652654	0.928348	0.513444	0.744095	0.972031	0.527368	0.494287	0.602829	0.592834
0.435196	0.272807	0.452254	0.793464	0.817291	0.828245	0.407518	0.441518	0.358966	0.619741
0.692512	0.368151	0.821543	0.583707	0.802354	0.133831	0.569521	0.474516	0.437608	0.961559
0.678823	0.930602	0.657348	0.025057	0.294093	0.499623	0.006423	0.290613	0.325204	0.044439
0.642075	0.029842	0.289042	0.891009	0.813844	0.973093	0.952871	0.361623	0.709933	0.466955
0.174285	0.863244	0.133649	0.773819	0.891664	0.246417	0.272407	0.517658	0.132225	0.795514
0.951401	0.921291	0.210993	0.369411	0.196909	0.054389	0.364475	0.716718	0.096843	0.308418
0.186824	0.005407	0.310843	0.998118	0.725887	0.143171	0.293721	0.841304	0.661969	0.409622
0.105673	0.026338	0.878006	0.105936	0.612556	0.124601	0.922558	0.648985	0.896805	0.737256
0.801080	0.619461	0.933720	0.275881	0.637352	0.644996	0.713379	0.302687	0.904515	0.457172
0.101214	0.236405	0.945199	0.005975	0.893786	0.082317	0.648743	0.511871	0.298942	0.121573
0.177754	0.930066	0.390527	0.575622	0.390428	0.600575	0.460949	0.191600	0.910079	0.099444
0.846157	0.322467	0.156607	0.253388	0.739021	0.133498	0.293141	0.144834	0.626600	0.045169
0.812147	0.306383	0.201517	0.306651	0.827112	0.277716	0.660224	0.268538	0.518416	0.579216
0.691055	0.059046	0.104390	0.427038	0.148688	0.480788	0.026511	0.572705	0.745522	0.986078
0.483819	0.797573	0.174899	0.892670	0.118990	0.813221	0.857964	0.279164	0.883509	0.154562
0.165133	0.985134	0.214681	0.595309	0.741697	0.418602	0.301917	0.338913	0.680062	0.097350
0.281668	0.476899	0.839512	0.057760	0.474156	0.898409	0.482638	0.198725	0.888281	0.018872
0.554337	0.350955	0.942401	0.526759	0.509846	0.408165	0.800079	0.789263	0.564192	0.140684

Table I.6 1,000 Random Numbers Uniformly Distributed between Zero and One (continued)

0.873143	0.349662	0.238282	0.383195	0.568383	0.298471	0.490431	0.731405	0.339906	0.431645
0.401675	0.061151	0.771468	0.795760	0.365952	0.221234	0.947374	0.375686	0.828215	0.113060
0.574987	0.154831	0.808117	0.723544	0.134014	0.360957	0.166572	0.112314	0.242857	0.309290
0.745415	0.929459	0.425406	0.118845	0.386382	0.867386	0.808757	0.009573	0.229879	0.849242
0.613554	0.926550	0.857632	0.014438	0.004214	0.592513	0.280223	0.283447	0.943793	0.205750
0.880368	0.303741	0.247850	0.341580	0.867155	0.542130	0.473418	0.650251	0.326222	0.036285
0.567556	0.183534	0.696381	0.373333	0.716762	0.526636	0.306862	0.904790	0.151931	0.328792
0.280015	0.237361	0.336240	0.424191	0.192603	0.770194	0.284572	0.992475	0.308979	0.698329
0.502862	0.818555	0.238758	0.057148	0.461531	0.904929	0.521982	0.599127	0.239509	0.424858
0.738375	0.794328	0.305231	0.887161	0.021104	0.469779	0.913966	0.266514	0.647901	0.246223
0.366209	0.749763	0.634971	0.261038	0.869115	0.787951	0.678287	0.667142	0.216531	0.763214
0.739267	0.554299	0.979969	0.489597	0.545130	0.931869	0.096443	0.374089	0.140070	0.840563
0.375690	0.866922	0.256930	0.518074	0.217373	0.027043	0.801938	0.040364	0.624283	0.292810
0.894101	0.178824	0.443631	0.110614	0.556232	0.969563	0.291364	0.695764	0.306903	0.303885
0.668169	0.296926	0.324041	0.616290	0.799426	0.372555	0.070954	0.045748	0.505327	0.027722
0.470107	0.135634	0.271284	0.494071	0.485610	0.382772	0.418470	0.004082	0.298068	0.539847
0.047906	0.694949	0.309033	0.223989	0.008978	0.383695	0.479858	0.894958	0.597796	0.162072
0.917713	0.072793	0.107402	0.007328	0.176598	0.576809	0.052969	0.421803	0.737514	0.340966
0.839439	0.338565	0.254833	0.924413	0.871833	0.480599	0.172846	0.736102	0.471802	0.783451
0.488244	0.260352	0.129716	0.153558	0.305933	0.777100	0.111924	0.412930	0.601453	0.083217
0.488369	0.485094	0.322236	0.894264	0.781546	0.770237	0.707400	0.587451	0.571609	0.981580
0.311380	0.270400	0.807264	0.348433	0.172763	0.914856	0.011893	0.014317	0.820797	0.261767
0.028802	0.072165	0.944160	0.804761	0.770481	0.104256	0.112919	0.184068	0.940946	0.238087
0.466082	0.603884	0.959713	0.547834	0.487552	0.455150	0.240324	0.428921	0.648821	0.277620
0.720229	0.575779	0.939622	0.234554	0.767389	0.735335	0.941002	0.794021	0.291615	0.165732
0.861579	0.778039	0.331677	0.608231	0.646094	0.498720	0.140520	0.259197	0.782477	0.922273
0.849884	0.917789	0.816247	0.572502	0.753757	0.857324	0.988330	0.597085	0.186087	0.771997
0.989999	0.994007	0.349735	0.954437	0.741124	0.791852	0.986074	0.444554	0.177531	0.743725
0.337214	0.987184	0.344245	0.039033	0.549585	0.688526	0.225470	0.556251	0.157058	0.681447
0.706330	0.082994	0.299909	0.613361	0.031334	0.941102	0.772731	0.198070	0.460602	0.778659
0.417239	0.916556	0.707773	0.249767	0.169301	0.914420	0.732687	0.934912	0.985594	0.726957
0.653326	0.529996	0.305465	0.181747	0.153359	0.353168	0.673377	0.448970	0.546347	0.885438
0.099373	0.156385	0.067157	0.755573	0.689979	0.494021	0.996216	0.051811	0.049321	0.595525
0.860299	0.210143	0.026232	0.838499	0.108975	0.455260	0.320633	0.150619	0.445073	0.275619
0.067160	0.791992	0.363875	0.825052	0.047561	0.311194	0.447486	0.971659	0.876616	0.455018
0.944317	0.348844	0.210015	0.769274	0.253032	0.239894	0.208165	0.600014	0.945046	0.505316
0.917419	0.185575	0.743859	0.655124	0.185320	0.237660	0.271534	0.949825	0.441666	0.811135
0.365705	0.800723	0.116707	0.386073	0.837800	0.244896	0.337304	0.869528	0.845737	0.194553
0.911453	0.591254	0.920222	0.707522	0.782902	0.092884	0.426444	0.320336	0.226369	0.377845

Table I.6 1,000 Random Numbers Uniformly Distributed between Zero and One (continued)

0.027171	0.058193	0.726183	0.057705	0.935493	0.688071	0.752543	0.932781	0.048914	0.591035
0.768066	0.387888	0.655990	0.690208	0.746739	0.936409	0.685458	0.090931	0.242120	0.067899
0.052305	0.899285	0.092643	0.058916	0.826653	0.772790	0.785028	0.967761	0.588503	0.896590
0.623285	0.492051	0.644294	0.821341	0.600824	0.901289	0.774379	0.391874	0.810022	0.437879
0.624284	0.308522	0.208541	0.297156	0.576129	0.373705	0.370345	0.372748	0.965550	0.874416
0.853117	0.671602	0.018316	0.095780	0.871263	0.885420	0.919787	0.439594	0.460586	0.629443
0.967796	0.933631	0.397054	0.682343	0.505977	0.406611	0.539543	0.066152	0.885414	0.857606
0.759450	0.768853	0.115419	0.744466	0.607572	0.179839	0.413809	0.228607	0.362857	0.826932
0.514703	0.108915	0.864053	0.076280	0.352557	0.674917	0.572689	0.588574	0.596215	0.639101
0.826296	0.264540	0.255775	0.180449	0.405715	0.740170	0.423514	0.537793	0.877436	0.512284
0.354198	0.792775	0.051583	0.806962	0.385851	0.655314	0.046701	0.860466	0.848112	0.515684
0.744807	0.960789	0.123099	0.163569	0.621969	0.571558	0.482449	0.346358	0.795845	0.207558
0.642312	0.356643	0.797708	0.505570	0.418534	0.634642	0.033111	0.393330	0.105093	0.328848
0.824625	0.855876	0.770743	0.678619	0.927298	0.204828	0.831460	0.979875	0.566627	0.056160
0.755877	0.679791	0.442388	0.899944	0.563383	0.197074	0.679568	0.244433	0.786084	0.337991
0.625370	0.967123	0.321605	0.697578	0.122418	0.475395	0.068207	0.070374	0.353248	0.461960
0.124012	0.133851	0.761154	0.501578	0.204221	0.866481	0.925783	0.329001	0.327832	0.844681
0.825392	0.382001	0.847909	0.520741	0.404959	0.308849	0.418976	0.972838	0.452438	0.600528
0.999194	0.297058	0.617183	0.570478	0.875712	0.581618	0.284410	0.405575	0.362205	0.427077
0.536855	0.667083	0.636883	0.043774	0.113509	0.980045	0.237797	0.618925	0.670767	0.814902
0.361632	0.797162	0.136063	0.487575	0.682796	0.952708	0.759989	0.058556	0.292400	0.871674
0.923253	0.479871	0.022855	0.673915	0.733795	0.811955	0.417970	0.095675	0.831670	0.043950
0.845432	0.202336	0.348421	0.050704	0.171916	0.600557	0.284838	0.606715	0.758190	0.394811

I.7 Stem and Leaf Display

The construction of a **stem and leaf display** is a simple way to generate a crude histogram of the data quickly. The "stems" of such a display are the most significant digits of the data. Consider the sample data of Section 8.2.2.2:

90.7, 83.5, 86.4, 88.5, 84.4, 74.2, 84.1, 87.6, 78.2, 77.6,
86.4, 76.3, 86.5, 77.4, 90.3, 90.1, 79.1, 92.4, 75.5, 80.5.

Here the data span three decades, so one might consider using the stems 70, 80 and 90. However, three is too few stems to be informative, just as three intervals would be too few for constructing a histogram. Therefore, for this example, each decade is divided into two parts. This results in the six stems 70, 75, 80, 85, 90, 95. The leaves are the least significant digits, so 90.7 has the stem 90 and the leaf 0.7. 77.4 has the stem 75 and the leaf 7.4. Note that even though the stem is 75, the leaf is *not* 2.4. The leaf is kept as 7.4 so that the data can be read directly from the display without any calculations.

As shown in the top part of Figure I.1, simply arrange the leaves of the data into rows, one stem per row. The result is a quick histogram of the data. In order to ensure this, the same number of digits should be used for each leaf, so that each occupies the same amount of horizontal space.

If the stems are arranged in increasing order, as shown in the bottom half of Figure I.1, it is easy to pick out the minimum (74.2), the maximum (92.4), and the median (between 84.1 and 84.4).

A stem and leaf display (or histogram) with two peaks may indicate that residual radioactivity is distributed over only a portion of the survey unit. Further information on the construction and interpretation of data plots is given in EPA QA/G-9 (EPA 1996a).

Stem	Leaves
70	4.2
75	8.2, 7.6, 6.3, 7.4, 9.1, 5.5
80	3.5, 4.4, 4.1, 0.5
85	6.4, 8.5, 7.6, 6.4, 6.5
90	0.7, 0.3, 0.1, 2.4
95	

Stem	Sorted Leaves
70	4.2
75	5.5, 6.3, 7.4, 7.6, 8.2, 9.1
80	0.5, 3.5, 4.1, 4.4
85	6.4, 6.4, 6.5, 7.6, 8.5
90	0.1, 0.3, 0.7, 2.4
95	

Figure I.1 Example of a Stem and Leaf Display

I.8 Quantile Plots

A **Quantile plot** is constructed by first ranking the data from smallest to largest. Sorting the data is easy once the stem and leaf display has been constructed. Then, each data value is simply plotted against the percentage of the samples with that value or less. This percentage is computed from:

$$Percent = \frac{100(rank - 0.5)}{(number\ of\ data\ points)} \qquad \text{(I-3)}$$

The results for the example data of Section I.7 are shown in Table I.7. The Quantile plot for this example is shown in Figure I.2.

The slope of the curve in the Quantile plot is an indication of the amount of data in a given range of values. A small amount of data in a range will result in a large slope. A large amount of data in a range of values will result in a more horizonal slope. A sharp rise near the bottom or the top is an indication of asymmetry. Sudden changes in slope, or notably flat or notably steep areas may indicate peculiarities in the survey unit data needing further investigation.

Table I.7 Data for Quantile Plot

Data:	74.2	75.5	76.3	77.4	77.6	78.2	79.1	80.5	83.5	84.1
Rank:	1	2	3	4	5	6	7	8	9	10
Percent:	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5
Data:	84.4	86.4	86.4	86.5	87.6	88.5	90.1	90.3	90.7	92.4
Rank:	11	12.5	12.5	14	15	16	17	18	19	20
Percent:	52.5	60.0	60.0	67.5	72.5	77.5	82.5	87.5	92.5	97.5

A useful aid to interpreting the quantile plot is the addition of boxes containing the middle 50% and middle 75% of the data. These are shown as the dashed lines in Figure I.2. The 50% box has its upper right corner at the 75th percentile and its lower left corner at the 25th percentile. These points are also called the Quartiles. These are ~78 and ~88, respectively, as indicated by the dashed lines. They bracket the middle half of the data values. The 75% box has its upper right corner at the 87.5th percentile and its lower left corner at the 12.5th percentile. A sharp increase within the 50% box can indicate two or more modes in the data. Outside the 75% box, sharp increases can indicate outliers. The median (50th percentile) is indicated by the heavy solid line at the value ~84, and can be used as an aid to judging the symmetry of the data distribution. There are no especially unusual features in the example Quantile plot shown in Figure I.2, other than the possibility of slight asymmetry around the median.

Another Quantile plot, for the example data of Section 8.3.3, is shown in Figure I.3.

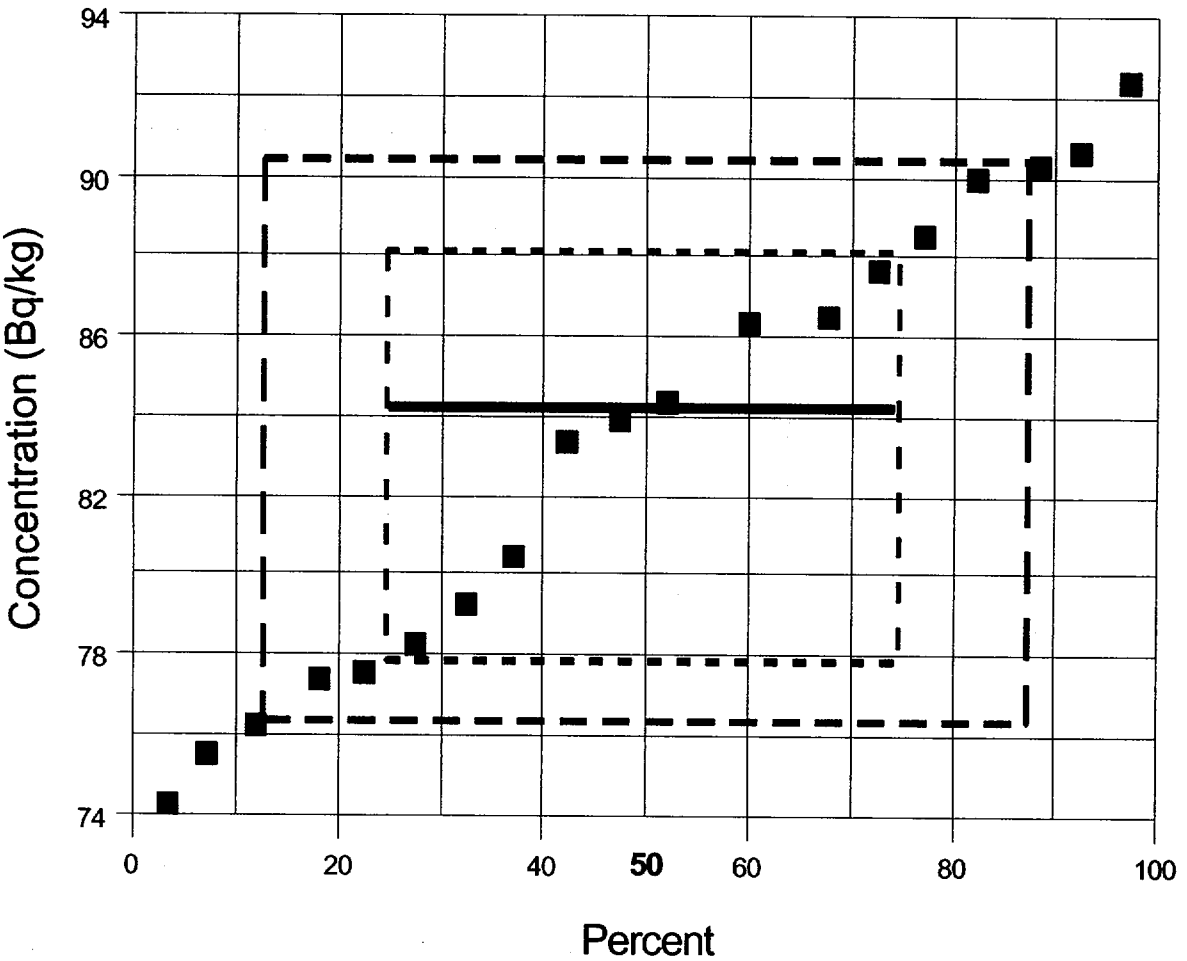

Figure I.2 Example of a Quantile Plot

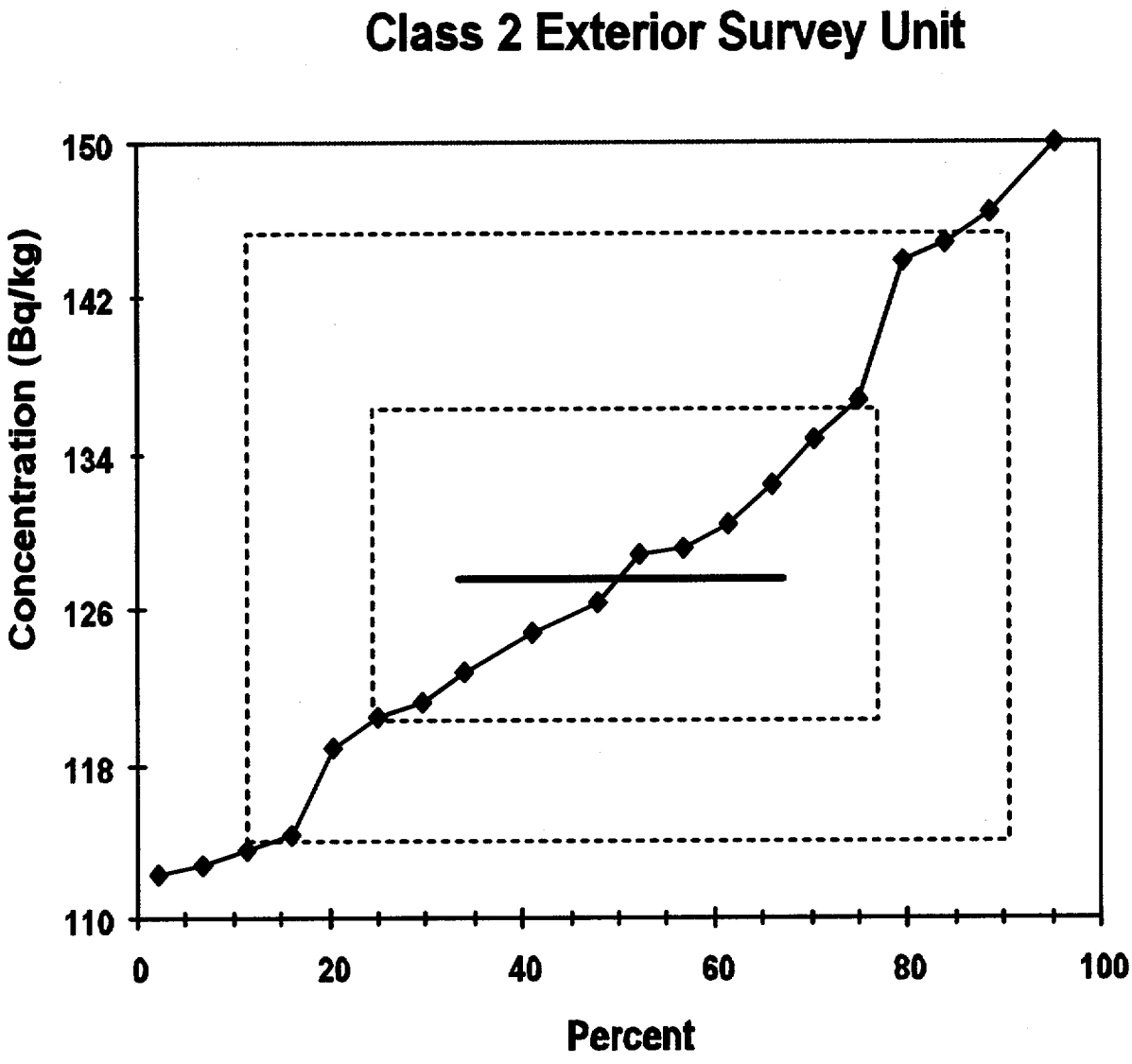

Figure I.3 Quantile Plot for Example Class 2 Exterior Survey Unit of Section 8.3.3.

A **Quantile-Quantile plot** is extremely useful for comparing two sets of data. Suppose the following 17 concentration values were obtained in a reference area corresponding to the example survey unit data of Section I.7:

92.1, 83.2, 81.7, 81.8, 88.5, 82.4, 81.5, 69.7, 82.4, 89.7,
81.4, 79.4, 82.0, 79.9, 81.1, 59.4, 75.3.

A Quantile-Quantile plot can be constructed to compare the distribution of the survey unit data, Y_j, j=1,...n, with the distribution of the reference area data X_i, i=1,... m. (If the reference area data set were the larger, the roles of X and Y would be reversed.) The data from each set are ranked separately from smallest to largest. This has already been done for the survey unit data in Table I.7. For the reference area data, we obtain the results in Table I.8.

Table I.8 Ranked Reference Area Concentrations

Data:	59.4	69.7	75.3	79.4	79.9	81.1	81.4	81.5	81.7	81.8
Rank:	1	2	3	4	5	6	7	8	9	10
Data:	82.0	82.4	82.4	83.2	88.5	89.7	92.1			
Rank:	11	12.5	12.5	14	15	16	17			

The median for the reference area data is 81.7, the sample mean is 80.7, and the sample standard deviation is 7.5.

For the larger data set, the data must be interpolated to match the number of points in the smaller data set. This is done by computing

$$\text{í}_1 = 0.5(n/m) + 0.5 \quad \textit{and} \quad \text{í}_{i+1} = \text{í}_i + (n/m) \quad \textit{for } i = 1,...m-1, \tag{I-4}$$

where m is the number of points in the smaller data set and n is the number of points in the larger data set. For each of the ranks, i, in the smaller data set, a corresponding value in the larger data set is found by first decomposing v_i into its integer part, j, and its fractional part, g.

Then the interpolated values are computed from the relationship:

$$Z_i = (1\text{-}g)\, Y_j + g\, Y_{j+1}\,. \qquad \text{(I-5)}$$

The results of these calculations are shown in Table I.9.

Table I.9 Interpolated Ranks for Survey Unit Concentrations

Rank	1	2	3	4	5	6	7	8	9	10
v_i	1.09	2.26	3.44	4.62	5.79	6.97	8.15	9.33	10.50	11.68
Z_i	74.3	75.7	76.8	77.5	78.1	79.1	80.9	83.7	84.3	85.8
X_i	59.4	69.7	75.3	79.4	79.7	81.1	81.4	81.5	81.7	81.8

Rank	11	12.5	12.5	14	15	16	17
v_i	12.85	14.03	15.21	16.38	17.56	18.74	19.91
Z_i	86.4	86.5	87.8	89.1	90.2	90.6	92.3
X_i	82.0	82.4	82.4	83.2	88.5	89.7	92.1

Finally, Z_i is plotted against X_i to obtain the Quantile-Quantile plot. This example is shown in Figure I.4.

The Quantile-Quantile Plot is valuable because it provides a direct visual comparison of the two data sets. If the two data distributions differ only in location (*e.g.* mean) or scale (*e.g.* standard deviation), the points will lie on a straight line. If the two data distributions being compared are identical, all of the plotted points will lie on the line $Y=X$. Any deviations from this would point to possible differences in these distributions. The middle data point plots the median of Y against the median of X. That this point lies above the line $Y=X$, in the example of Figure 8.4, shows that the median of Y is larger than the median of X. Indeed, the cluster of points above the line $Y = X$ in the region of the plot where the data points are dense, is an indication that the central portion of the survey unit distribution is shifted toward higher values than the reference area distribution. This could imply that there is residual radioactivity in the survey unit. This should be tested using the nonparametric statistical tests described in Chapter 8.

Another Quantile-Quantile plot, for the Class 1 Interior Survey Unit example data, is shown in Figure A.8.

Further information on the interpretation of Quantile and Quantile-Quantile plots are given in EPA QA/G-9 (EPA 1996a).

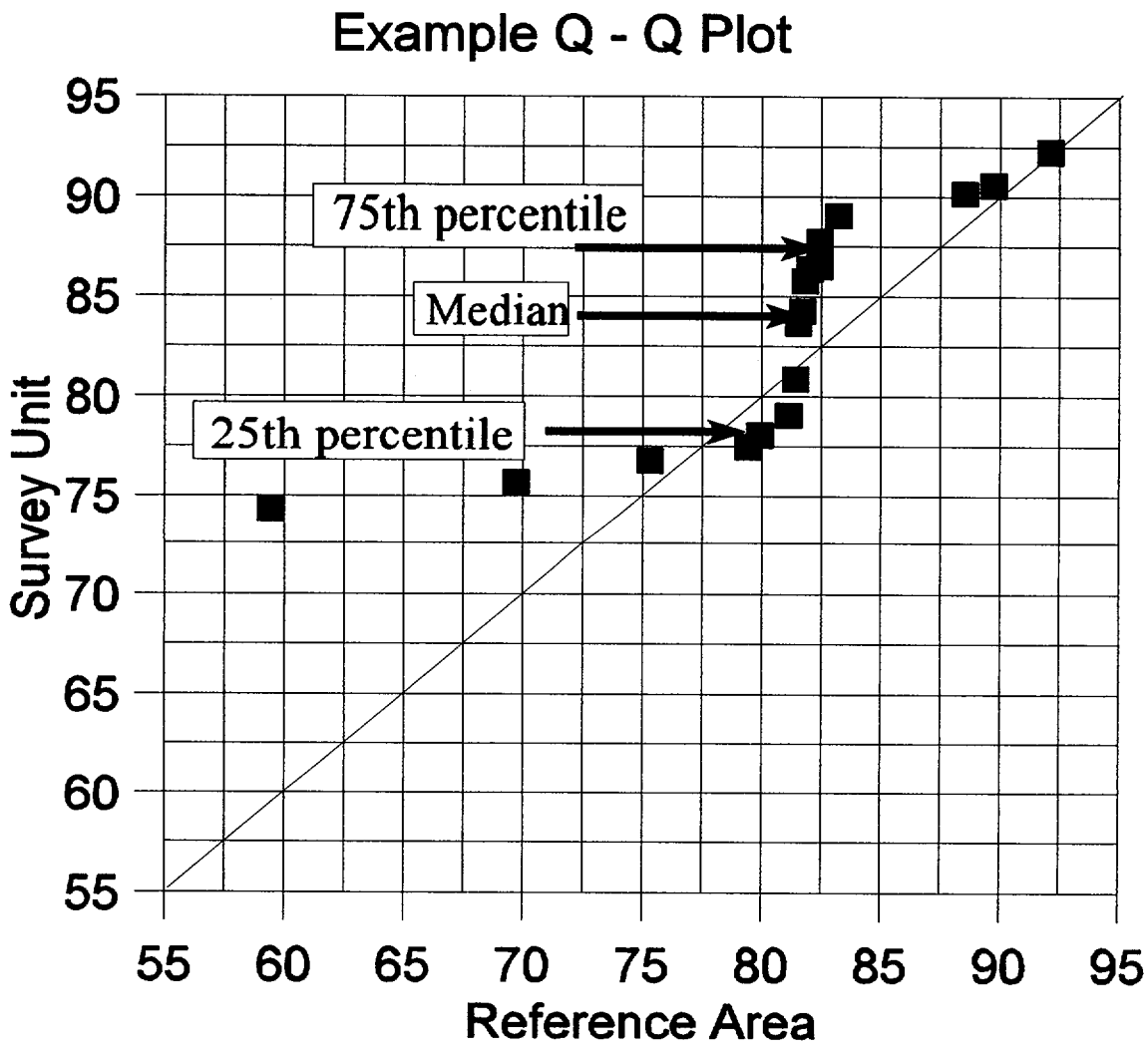

Figure I.4 Example Quantile-Quantile Plot

I.9 Power Calculations for the Statistical Tests

I.9.1 Power of the Sign Test

The power of the Sign test for detecting residual radioactivity at the concentration level LBGR = DGCL - Δ, may be found using equation I-6.

$$1 - \beta = 1 - \sum_{i=0}^{k} \binom{N}{i} [q^*]^i [1-q^*]^{N-i} \approx 1 - \Phi\left(\frac{k - Nq^*}{\sqrt{Nq^*(1-q^*)}}\right) \qquad \text{(I-6)}$$

with

$$q^* = \Phi(\Delta/\sigma) \qquad \text{(I-7)}$$

The function Φ(z) is the standard normal cumulative distribution function tabulated in Table I.1. Note that if Δ/σ is large, q^* approaches one, and the power also approaches one. This calculation can be performed for other values, Δ*, in order to construct a power curve for the test. These calculations can also be performed using the standard deviation of the actual measurement data, *s*, in order to construct a retrospective power curve for the test. This is an important step when the null hypothesis is not rejected, since it demonstrates whether the DQOs have been met.

The retrospective power curve for the Sign test can be constructed using Equations I-6 and I-7, together with the actual number of concentration measurements obtained, N. The power as a function of Δ/σ is calculated. The values of Δ/σ are converted to concentration using:

Concentration = $DCGL_W$ - (Δ/σ)(observed standard deviation).

The results for the Class 3 Exterior Survey Unit example of Section 8.3.4 are plotted in Figure I.5. This figure shows the probability that the survey unit would have passed the release criterion using the Sign test versus concentration of residual radioactivity. This curve shows that the data quality objectives were met, despite the fact that the actual standard deviation was larger than that used in designing the survey. This is primarily due to the additional 20% that was added to the sample size, and also that sample sizes were always rounded up. The curve shows that a survey unit with less than 135 Bq/kg would almost always pass, and that a survey unit with more than 145 Bq/kg would almost always fail.

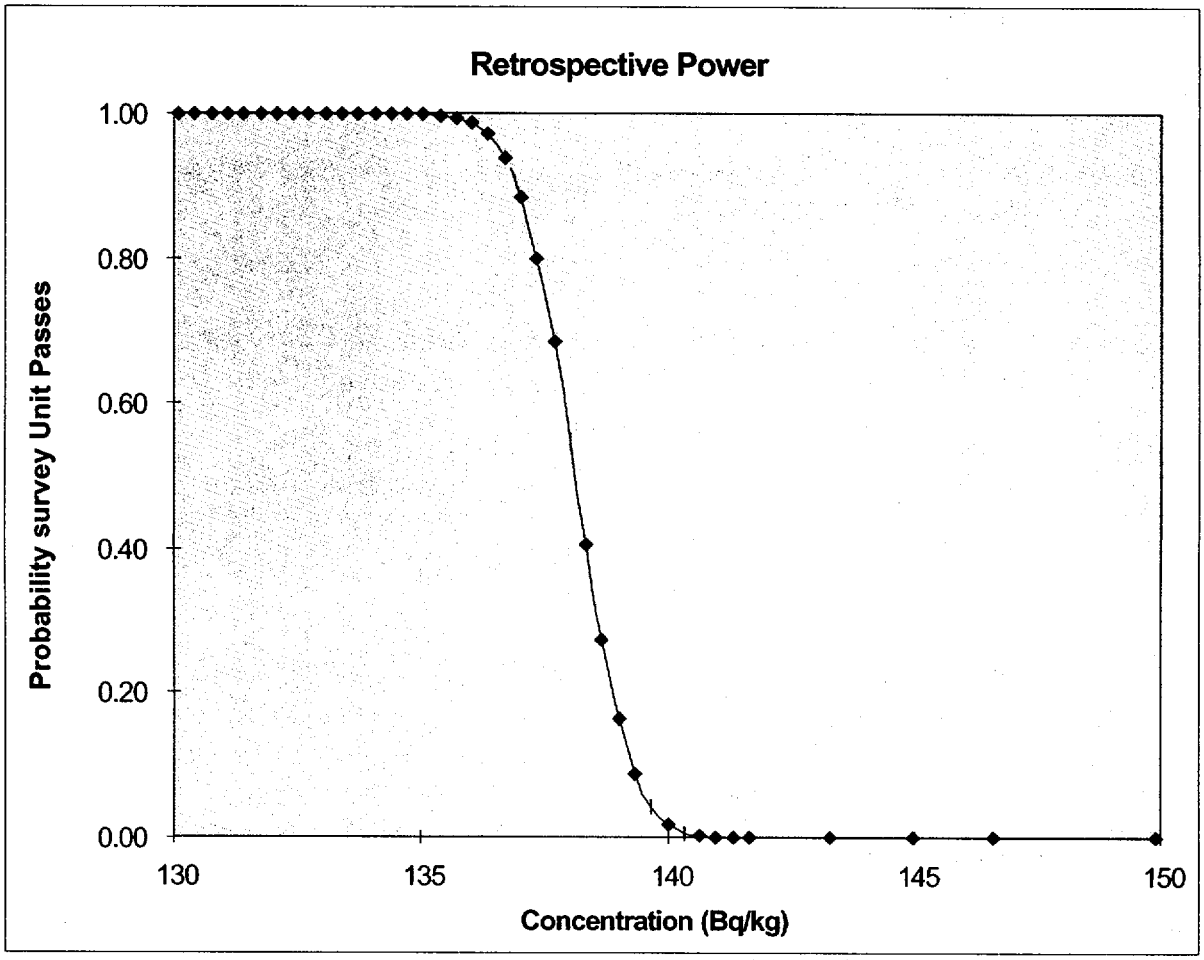

Figure I.5 Retrospective Power Curve for Class 3 Exterior Survey Unit

I.9.2 Power of the Wilcoxon Rank Sum Test

The power of the WRS test is computed from

$$Power = 1 - \Phi\left[\frac{W_c - 0.5 - 0.5m(m+1) - E(W_{MW})}{\sqrt{Var(W_{MW})}}\right] \quad \text{(I-8)}$$

where W_c is the critical value found in Table I.4 for the appropriate vales of α, n and m. Values of $\Phi(z)$, the standard normal cumulative distribution function, are given in Table I.1.

$W_{MW} = W_r - 0.5m(m+1)$ is the Mann-Whitney form of the WRS test statistic. Its mean is

$$E(W_{MW}) = mnP_r \quad \text{(I-9)}$$

and its variance is

$$\text{Var}(W_{MW}) = mnP_r(1-P_r) + mn(n+m-2)(p_2 - P_r^2) \quad \text{(I-10)}$$

Values of P_r and p_2 as a function of Δ/σ are given in Table I.10.

The power calculated in Equation I-8 is an approximation, but the results are generally accurate enough to be used to determine if the sample design achieves the DQOs.

The retrospective power curve for the WRS test can be constructed using Equations I-8, I-9, and I-10, together with the actual number of concentration measurements obtained, N. The power as a function of Δ/σ is calculated. The values of Δ/σ are converted to dpm/100 cm^2 using:

dpm/100 cm^2 = DCGL - (Δ/σ)(observed standard deviation).

The results for this example are plotted in Figure I.6, showing the probability that the survey unit would have passed the release criterion using the WRS test versus dpm of residual radioactivity. This curve shows that the data quality objectives were easily achieved. The curve shows that a survey unit with less than 4,500 dpm/100 cm^2 above background would almost always pass, and that one with more than 5,100 dpm/100 cm^2 above background would almost always fail.

Table I.10 Values of P_r and p_2 for Computing the Mean and Variance of W_{MW}

Δ/σ	P_r	p_2	Δ/σ	P_r	p_2
-6.0	1.11E-05	1.16E-07	0.7	0.689691	0.544073
-5.0	0.000204	6.14E-06	0.8	0.714196	0.574469
-4.0	0.002339	0.000174	0.9	0.737741	0.604402
-3.5	0.006664	0.000738	1.0	0.760250	0.633702
-3.0	0.016947	0.002690	1.1	0.781662	0.662216
-2.5	0.038550	0.008465	1.2	0.801928	0.689800
-2.0	0.078650	0.023066	1.3	0.821015	0.716331
-1.9	0.089555	0.027714	1.4	0.838901	0.741698
-1.8	0.101546	0.033114	1.5	0.855578	0.765812
-1.7	0.114666	0.039348	1.6	0.871050	0.788602
-1.6	0.128950	0.046501	1.7	0.885334	0.810016
-1.5	0.144422	0.054656	1.8	0.898454	0.830022
-1.4	0.161099	0.063897	1.9	0.910445	0.848605
-1.3	0.178985	0.074301	2.0	0.921350	0.865767
-1.2	0.198072	0.085944	2.1	0.931218	0.881527
-1.1	0.218338	0.098892	2.2	0.940103	0.895917
-1.0	0.239750	0.113202	2.3	0.948062	0.908982
-0.9	0.262259	0.128920	2.4	0.955157	0.920777
-0.8	0.285804	0.146077	2.5	0.961450	0.931365
-0.7	0.310309	0.164691	2.6	0.967004	0.940817
-0.6	0.335687	0.184760	2.7	0.971881	0.949208
-0.5	0.361837	0.206266	2.8	0.976143	0.956616
-0.4	0.388649	0.229172	2.9	0.979848	0.963118
-0.3	0.416002	0.253419	3.0	0.983053	0.968795
-0.2	0.443769	0.278930	3.1	0.985811	0.973725
-0.1	0.471814	0.305606	3.2	0.988174	0.977981
0.0	0.500000	0.333333	3.3	0.990188	0.981636
0.1	0.528186	0.361978	3.4	0.991895	0.984758
0.2	0.556231	0.391392	3.5	0.993336	0.987410
0.3	0.583998	0.421415	4.0	0.997661	0.995497
0.4	0.611351	0.451875	5.0	0.999796	0.999599
0.5	0.638163	0.482593	6.0	0.999989	0.999978
0.6	0.664313	0.513387			

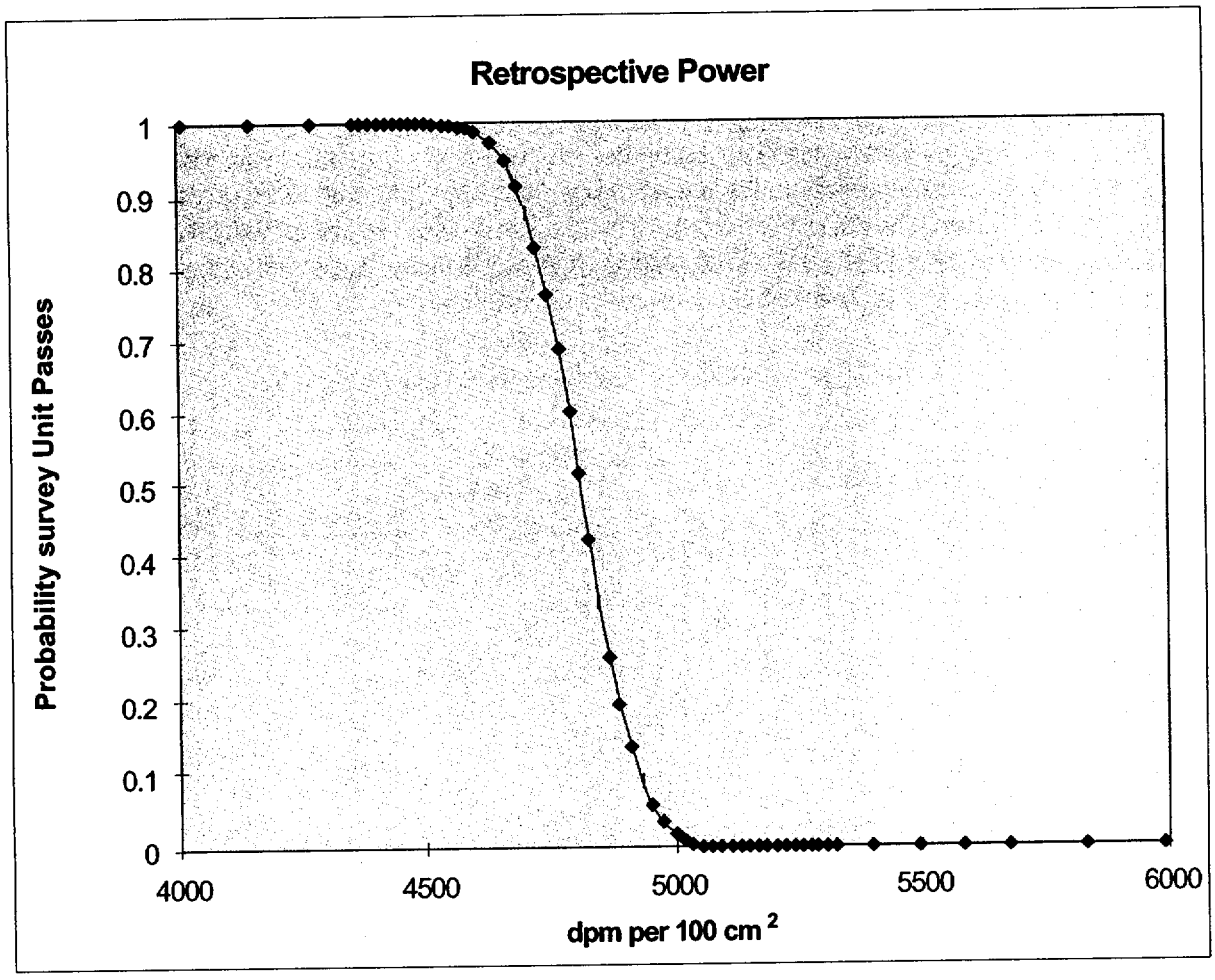

Figure I.6 Retrospective Power Curve for Class 2 Interior Drywall Survey Unit

I.10 Spreadsheet Formulas for the Wilcoxon Rank Sum Test

The analysis for the WRS test is very well suited for calculation on a spreadsheet. This is how the analysis discussed above was done. This particular example was constructed using Excel 5.0™. The formula sheet corresponding to Table 8.6 is given in Table I.11. The function in Column D of Table I.11 calculates the ranks of the data. The RANK function in Excel™ does not return tied ranks in the way needed for the WRS. The COUNTIF function is used to correct for this. Column E simply picks out the reference area ranks from Column D.

Table I.11 Spreadsheet Formulas Used in Table 8.6

	A	B	C	D	E
1	**Data**	**Area**	**Adjusted Data**	**Ranks**	**Reference Area Ranks**
2	49	R	=IF(B2="R",A2+160,A2)	=RANK(C2,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C2) - 1) / 2	=IF(B2="R",D2,0)
3	35	R	=IF(B3="R",A3+160,A3)	=RANK(C3,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C3) - 1) / 2	=IF(B3="R",D3,0)
4	45	R	=IF(B4="R",A4+160,A4)	=RANK(C4,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C4) - 1) / 2	=IF(B4="R",D4,0)
5	45	R	=IF(B5="R",A5+160,A5)	=RANK(C5,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C5) - 1) / 2	=IF(B5="R",D5,0)
6	41	R	=IF(B6="R",A6+160,A6)	=RANK(C6,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C6) - 1) / 2	=IF(B6="R",D6,0)
7	44	R	=IF(B7="R",A7+160,A7)	=RANK(C7,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C7) - 1) / 2	=IF(B7="R",D7,0)
8	48	R	=IF(B8="R",A8+160,A8)	=RANK(C8,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C8) - 1) / 2	=IF(B8="R",D8,0)
9	37	R	=IF(B9="R",A9+160,A9)	=RANK(C9,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C9) - 1) / 2	=IF(B9="R",D9,0)
10	46	R	=IF(B10="R",A10+160,A10)	=RANK(C10,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C10) - 1) / 2	=IF(B10="R",D10,0)
11	42	R	=IF(B11="R",A11+160,A11)	=RANK(C11,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C11) - 1) / 2	=IF(B11="R",D11,0)
12	47	R	=IF(B12="R",A12+160,A12)	=RANK(C12,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C12) - 1) / 2	=IF(B12="R",D12,0)
13	104	S	=IF(B13="R",A13+160,A13)	=RANK(C13,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C13) - 1) / 2	=IF(B13="R",D13,0)
14	94	S	=IF(B14="R",A14+160,A14)	=RANK(C14,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C14) - 1) / 2	=IF(B14="R",D14,0)
15	98	S	=IF(B15="R",A15+160,A15)	=RANK(C15,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C15) - 1) / 2	=IF(B15="R",D15,0)
16	99	S	=IF(B16="R",A16+160,A16)	=RANK(C16,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C16) - 1) / 2	=IF(B16="R",D16,0)
17	90	S	=IF(B17="R",A17+160,A17)	=RANK(C17,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C17) - 1) / 2	=IF(B17="R",D17,0)
18	104	S	=IF(B18="R",A18+160,A18)	=RANK(C18,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C18) - 1) / 2	=IF(B18="R",D18,0)
19	95	S	=IF(B19="R",A19+160,A19)	=RANK(C19,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C19) - 1) / 2	=IF(B19="R",D19,0)
20	105	S	=IF(B20="R",A20+160,A20)	=RANK(C20,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C20) - 1) / 2	=IF(B20="R",D20,0)
21	93	S	=IF(B21="R",A21+160,A21)	=RANK(C21,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C21) - 1) / 2	=IF(B21="R",D21,0)
22	101	S	=IF(B22="R",A22+160,A22)	=RANK(C22,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C22) - 1) / 2	=IF(B22="R",D22,0)
23	92	S	=IF(B23="R",A23+160,A23)	=RANK(C23,$C$2:$C$23,1)+(COUNTIF($C$2:$C$23,C23) - 1) / 2	=IF(B23="R",D23,0)
24			Sum=	=SUM(D2:D23)	=SUM(E2:E23)

I.11 Multiple Radionuclides

There are two cases to be considered when dealing with multiple radionuclides, namely 1) the radionuclide concentrations have a fairly constant ratio throughout the survey unit, or 2) the concentrations of the different radionuclides appear to be unrelated in the survey unit. In statistical terms, we are concerned about whether the concentrations of the different radionuclides are correlated or not. A simple way to judge this would be to make a scatter plot of the concentrations against each other, and see if the points appear to have an underlying linear pattern. The correlation coefficient can also be computed to see if it lies nearer to zero than to one. One could also perform a curve fit and test the significance of the result. Ultimately, however, sound judgement must be used in interpreting the results of such calculations. If there is no physical reason for the concentrations to be related, they probably are not. Conversely, if there is sound evidence that the radionuclide concentrations should be related because of how they were treated, processed or released, this information should be used.

I.11.1 Using the Unity Rule

In either of the two above cases, the unity rule described in Section 4.3.3 is applied. The difference is in how it is applied. Suppose there are n radionuclides. If the concentration of radionuclide i is denoted by C_i, and its $DCGL_W$ is denoted by D_i, then the unity rule for the n radionuclides states that:

$$C_1 / D_1 + C_2 / D_2 + C_3 / D_3 + \cdots + C_n / D_n \leq 1 \qquad \text{(I-11)}$$

This will ensure that the total dose or risk due to the sum of all the radionuclides does not exceed the release criterion. Note that if D_{min} is the smallest of the DCGLs, then

$$(C_1 + C_2 + C_3 + \cdots + C_n)/D_{min} \leq C_1 / D_1 + C_2 / D_2 + C_3 / D_3 + \cdots + C_n / D_n \qquad \text{(I-12)}$$

so that the smallest DCGL may be applied to the total activity concentration, rather than using the unity rule. While this option may be considered, in many cases it will be too conservative to be useful.

I.11.2 Radionuclide Concentrations with Fixed Ratios

If there is an established ratio among the concentrations of the n radionuclides in a survey unit, then the concentration of every radionuclide can be expressed in terms of any one of them, e.g., radionuclide #1. The measured radionuclide is often called a *surrogate* radionuclide for the others.

If $C_2 = R_2 C_1, C_3 = R_3 C_1, \ldots, C_i = R_i C_1, \ldots, C_n = R_n C_1$

then

$$\begin{aligned} & C_1/D_1 + C_2/D_2 + C_3/D_3 + \cdots + C_n/D_n \\ &= C_1/D_1 + R_2 C_1/D_2 + R_3 C_1/D_3 + \cdots + R_n C_1/D_n \\ &= C_1 [1/D_1 + R_2/D_2 + R_3/D_3 + \cdots + R_n/D_n] \\ &= C_1/D_{total} \end{aligned} \quad \text{(I-13)}$$

where

$$D_{total} = 1/[1/D_1 + R_2/D_2 + R_3/D_3 + \cdots + R_n/D_n] \quad \text{(I-14)}$$

Thus, D_{total} is the $DCGL_W$ for the surrogate radionuclide when the concentration of that radionuclide represents all radionuclides that are present in the survey unit. Clearly, this scheme is applicable only when radionuclide specific measurements of the surrogate radionuclide are made. It is unlikely to apply in situations where the surrogate radionuclide appears in background, since background variations would tend to obscure the relationships between it and the other radionuclides.

Thus, in the case where there are constant ratios among radionuclide concentrations, the statistical tests are applied as if only the surrogate radionuclide were contributing to the residual radioactivity, with the $DCGL_W$ for that radionuclide replaced by D_{total}. For example, in planning the final status survey, only the expected standard deviation of the concentration measurements for the surrogate radionuclide is needed to calculate the sample size.

For the elevated measurement comparison, the $DCGL_{EMC}$ for the surrogate radionuclide is replaced by

$$E_{total} = 1/[1/E_1 + R_2/E_2 + R_3/E_3 + \cdots + R_n/E_n] \quad \text{(I-15)}$$

where E_i is the $DCGL_{EMC}$ for radionuclide i.

I.11.3 Unrelated Radionuclide Concentrations

If the concentrations of the different radionuclides appear to be unrelated in the survey unit, there is little alternative but to measure the concentration of each radionuclide and use the unity rule. The exception would be in applying the most restrictive $DCGL_W$ to all of the radionuclides, as mentioned later in this section.

Since the release criterion is

$$C_1/D_1 + C_2/D_2 + C_3/D_3 + \cdots + C_n/D_n \leq 1 \quad \text{(I-16)}$$

the quantity to be measured is the *weighted sum,* $T = C_1 / D_1 + C_2 / D_2 + C_3 / D_3 + \cdots + C_n / D_n$. The $DCGL_W$ for T is one. In planning the final status survey, the measurement standard deviation of the weighted sum, T, is estimated by

$$\sigma^2(T) = [\sigma(C_1)/ D_1]^2 + [\sigma(C_2)/ D_2]^2 + [\sigma(C_3)/ D_3]^2 + \cdots + [\sigma(C_n)/ D_n]^2 \qquad \text{(I-17)}$$

since the measured concentrations of the various radionuclides are assumed to be uncorrelated.

For the elevated measurement comparison, the inequality

$$C_1 / E_1 + C_2 / E_2 + C_3 / E_3 + \cdots + C_n / E_n \leq 1 \qquad \text{(I-18)}$$

is used, where E_i is the $DCGL_{EMC}$ for radionuclide i. For scanning, the most restrictive $DCGL_{EMC}$ should generally be used.

When some of the radionuclides also appear in background, the quantity $T = C_1 / D_1 + C_2 / D_2 + C_3 / D_3 + \cdots + C_n / D_n$ must also be measured in an appropriate reference area. If radionuclide i does not appear in background, set $C_i = 0$ in the calculation of T for the reference area.

Note that if there is a fixed ratio between the concentrations of some radionuclides, but not others, a combination of the method of this section with that of the previous section may be used. The appropriate value of D_{total} with the concentration of the measured surrogate radionuclide should replace the corresponding terms in equation I-17.

I.11.4 Example Application of WRS Test to multiple radionuclides

This section contains an example application of the nonparametric statistical methods in this report to sites that have residual radioactivity from more than one radionuclide. Consider a site with both ^{60}Co and ^{137}Cs contamination. ^{137}Cs appears in background from global atmospheric weapons tests at a typical concentration of about 1 pCi/g. Assume that the $DCGL_W$ for ^{60}Co is 2 pCi/g and for ^{137}Cs is 1.4 pCi/g. In disturbed areas, the background concentration of ^{137}Cs can vary considerably. An estimated spatial standard deviation of 0.5 pCi/g for ^{137}Cs will be assumed. During remediation, it was found that the concentrations of the two radionuclides were not well correlated in the survey unit. ^{60}Co concentrations were more variable than the ^{137}Cs concentrations, and 0.7 pCi/g is estimated for its standard deviation. Measurement errors for both ^{60}Co and ^{137}Cs using gamma spectrometry will be small compared to this. For the comparison to the release criteria, the weighted sum of the concentrations of these radionuclides is computed from:

Weighted sum = (^{60}Co concentration)/(^{60}Co $DCGL_W$) + (^{137}Cs Concentration)/(^{137}Cs $DCGL_W$)
= (^{60}Co concentration)/(2) + (^{137}Cs Concentration)/(1.4)

The variance of the weighted sum, assuming that the ^{60}Co and ^{137}Cs concentrations are spatially unrelated is

$\sigma^2 = [(^{60}Co \text{ Standard deviation})/(^{60}Co \text{ DCGL}_W)]^2 + [(^{137}Cs \text{ Standard Deviation})/(^{137}Cs \text{ DCGL}_W)]^2$
$= [(0.7)/(2)]^2 + [(0.5)/(1.4)]^2 = 0.25.$

Thus $\sigma = 0.5$. The $DCGL_W$ for the weighted sum is one. The null hypothesis is that the survey unit exceeds the release criterion. During the DQO process, the LBGR was set at 0.5 for the weighted sum, so that $\Delta = DCGL_W - LBGR = 1.0 - 0.5 = 0.5$, and $\Delta/\sigma = 0.5/0.5 = 1.0$. The acceptable error rates chosen were $\alpha = \beta = 0.05$. To achieve this, 32 samples each are required in the survey unit and the reference area.

The weighted sums are computed for each measurement location in both the reference area and the survey unit. The WRS test is then performed on the weighted sum. The calculations for this example are shown in Table I.12. The $DCGL_W$ (i.e., 1.0) is added to the weighted sum for each location in the reference area. The ranks of the combined survey unit and adjusted reference area weighted sums are then computed. The sum of the ranks of the adjusted reference area weighted sums is then compared to the critical value for $n = m = 32$, $\alpha = 0.05$, which is 1162 (see formula following Table I.4). In Table I.12, the sum of the ranks of the adjusted reference area weighted sums is 1281. This exceeds the critical value, so the null hypothesis is rejected. The survey unit meets the release criterion. The difference between the mean of the weighted sums in the survey unit and the reference area is 1.86 - 1.16 = 0.7. Thus, the estimated dose or risk due to residual radioactivity in the survey unit is 70% of the release criterion.

Table I.12 Example WRS Test for Two Radionuclides

	Reference Area		Survey Unit		Weighted Sum			Ranks	
	^{137}Cs	^{60}Co	^{137}Cs	^{60}Co	*Ref*	*Survey*	*Adj Ref*	*Survey*	*Adj Ref*
1	2.00	0	1.12	0.06	1.43	0.83	2.43	1	56
2	1.23	0	1.66	1.99	0.88	2.18	1.88	43	21
3	0.99	0	3.02	0.56	0.71	2.44	1.71	57	14
4	1.98	0	2.47	0.26	1.41	1.89	2.41	23	55
5	1.78	0	2.08	0.21	1.27	1.59	2.27	9	50
6	1.93	0	2.96	0.00	1.38	2.11	2.38	37	54
7	1.73	0	2.05	0.20	1.23	1.56	2.23	7	46
8	1.83	0	2.41	0.00	1.30	1.72	2.30	16	52
9	1.27	0	1.74	0.00	0.91	1.24	1.91	2	24
10	0.74	0	2.65	0.16	0.53	1.97	1.53	27	6
11	1.17	0	1.92	0.63	0.83	1.68	1.83	13	18
12	1.51	0	1.91	0.69	1.08	1.71	2.08	15	32
13	2.25	0	3.06	0.13	1.61	2.25	2.61	47	63
14	1.36	0	2.18	0.98	0.97	2.05	1.97	30	28
15	2.05	0	2.08	1.26	1.46	2.12	2.46	39	58
16	1.61	0	2.30	1.16	1.15	2.22	2.15	45	41
17	1.29	0	2.20	0.00	0.92	1.57	1.92	8	25
18	1.55	0	3.11	0.50	1.11	2.47	2.11	59	35
19	1.82	0	2.31	0.00	1.30	1.65	2.30	11	51
20	1.17	0	2.82	0.41	0.84	2.22	1.84	44	19
21	1.76	0	1.81	1.18	1.26	1.88	2.26	22	48
22	2.21	0	2.71	0.17	1.58	2.02	2.58	29	62
23	2.35	0	1.89	0.00	1.68	1.35	2.68	3	64
24	1.51	0	2.12	0.34	1.08	1.68	2.08	12	33
25	0.66	0	2.59	0.14	0.47	1.92	1.47	26	5
26	1.56	0	1.75	0.71	1.12	1.60	2.12	10	38
27	1.93	0	2.35	0.85	1.38	2.10	2.38	34	53
28	2.15	0	2.28	0.87	1.54	2.06	2.54	31	61
29	2.07	0	2.56	0.56	1.48	2.11	2.48	36	60
30	1.77	0	2.50	0.00	1.27	1.78	2.27	17	49
31	1.19	0	1.79	0.30	0.85	1.43	1.85	4	20
32	1.57	0	2.55	0.70	1.12	2.17	2.12	42	40
Avg	1.62	0	2.28	0.47	1.16	1.86	2.16	sum = 799	sum = 1281
Std Dev	0.43	0	0.46	0.48	0.31	0.36	0.31		

APPENDIX J

DERIVATION OF ALPHA SCANNING EQUATIONS PRESENTED IN SECTION 6.7.2.2

For alpha survey instrumentation with a background around one to three counts per minute, a single count will give a surveyor sufficient cause to stop and investigate further. Assuming this to be true, the probability of detecting given levels of alpha emitting radionuclides can be calculated by use of Poisson summation statistics.

Discussion

Experiments yielding numerical values for a random variable X, where X represents the number of events occurring during a given time interval or a specified region in space, are often called Poisson experiments (Walpole and Myers 1985). The probability distribution of the Poisson random variable X, representing the number of events occurring in a given time interval t, is given by:

$$P(x;\lambda t) = \frac{e^{-\lambda t}(\lambda t)^x}{x!}, \quad x = 0, 1, 2, \ldots \qquad \text{(J-1)}$$

where:

$P(x; \lambda t)$	=	probability of x events in time interval t
λ	=	Average number of events per unit time
λt	=	Average value expected

To define this distribution for an alpha scanning system, substitutions may be made giving:

$$P(n;m) = \frac{e^{-m} m^n}{n!} \qquad \text{(J-2)}$$

where:

P(n; m)	=	probability of getting n counts when the average number expected is m
m	=	λt , average number of counts expected
n	=	x, number of counts actually detected

For a given detector size, source activity, and scanning rate, the probability of getting *n* counts while passing over the source activity with the detector can be written as:

$$P(n;m) = \frac{e^{\frac{-GEd}{60v}}\left[\frac{GEd}{60v}\right]^n}{n!} = \frac{e^{\frac{-GEt}{60}}\left[\frac{GEt}{60}\right]^n}{n!} \quad \text{(J-3)}$$

where:

G	=	source activity (dpm)
E	=	detector efficiency (4π)
d	=	width of the detector in the direction of scan (cm)
v	=	scan speed (cm/s)
t	=	d/v, dwell time over source (s)

If it is assumed that the detector background is equal to zero, then the probability of observing greater than or equal to 1 count, $P(n \geq 1)$, within a time interval t is:

$$P(n \geq 1) = 1 - P(n = 0) \quad \text{(J-4)}$$

If it is also assumed that a single count is sufficient to cause a surveyor to stop and investigate further, then:

$$P(n \geq 1) = 1 - P(n = 0) = 1 - e^{-\frac{GEd}{60v}} \quad \text{(J-5)}$$

Figures J.1 through J.3 show this function plotted for three different detector sizes and four different source activity levels. Note that the source activity levels are given in terms of areal activity values (dpm per 100 cm^2), the probe sizes are the dimensions of the probes in line with the direction of scanning, and the detection efficiency has been assumed to be 15%. The assumption is made that the areal activity is contained within a 100 cm^2 area and that the detector completely passes over the area either in one or multiple passes.

Once a count has been recorded and the surveyor stops, the surveyor should wait a sufficient period of time such that if the guideline level of contamination is present, the probability of getting another count is at least 90%. This minimum time interval can be calculated for given contamination guideline values by substituting the following parameters into Equation J-5 and solving:

$P(\geq 1) = 0.9$

$d/v = t$

$G = \frac{CA}{100}$

where:

C = contamination guideline (dpm/100 cm^2)

A = Detector area (cm^2)

Giving:

$$t = \frac{13800}{CAE} \qquad \text{(J-6)}$$

Equation J-3 can be solved to give the probability of getting any number of counts while passing over the source area, although the solutions can become long and complex. Many portable proportional counters have background count rates on the order of 5 to 10 counts per minute and a single count will not give a surveyor cause to stop and investigate further. If a surveyor did stop for every count, and subsequently waited a sufficiently long period to make sure that the previous count either was or wasn't caused by an elevated contamination level, little or no progress would be made. For these types of instruments, the surveyor usually will need to get at least 2 counts while passing over the source area before stopping for further investigation. Assuming this to be a valid assumption, Equation J-3 can be solved for $n \geq 2$ as follows:

$$\begin{aligned} P(n \geq 2) &= 1 - P(n=0) - P(n=1) \\ &= 1 - e^{-\frac{(GE+B)t}{60}} - \frac{(GE+B)t}{60} e^{-\frac{(GE+B)t}{60}} \\ &= 1 - e^{-\frac{(GE+B)t}{60}} \left(1 + \frac{(GE+B)t}{60}\right) \end{aligned} \qquad \text{(J-7)}$$

Where:

P(n≥2) = probability of getting 2 or more counts during the time interval t

P(n=0) = probability of not getting any counts during the time interval t

P(n=1) = probability of getting 1 count during the time interval t

B = background count rate (cpm)

All other variables are the same as in Equation J-3.

Figures J-4 through J-7 show this function plotted for three different probe sizes and three different source activity levels. The same assumptions were made when calculating these curves as were made for Figures J-1 through J-3 except that the background was assumed to be 7 counts per minute.

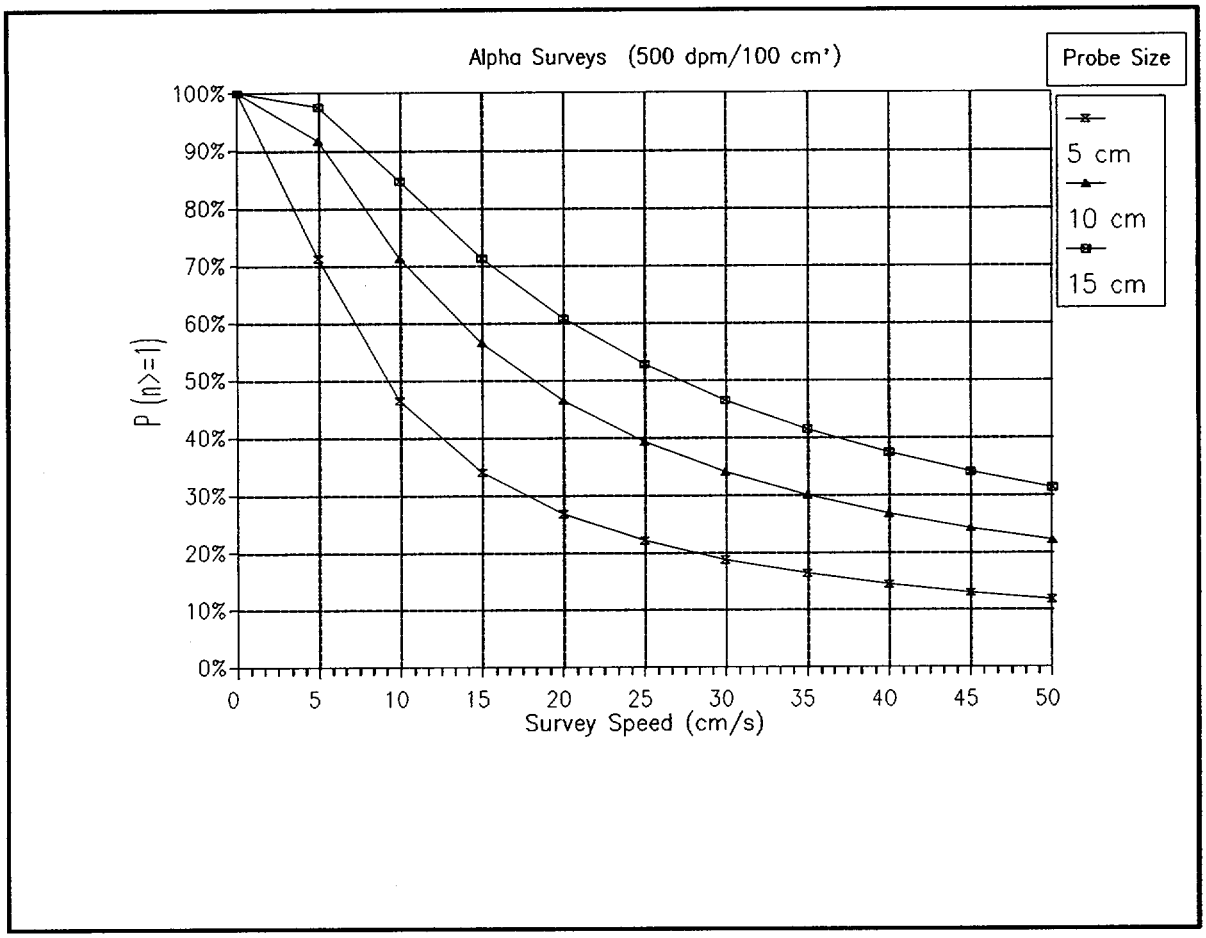

Figure J.1 **Probability (P) of getting one or more counts when passing over a 100 cm^2 area contaminated at 500 dpm/100 cm^2 alpha. The chart shows the probability versus scanning speed for three different probe sizes. The probe size denotes the dimensions of the probes which are in line with the direction of scanning. A detection efficiency of 15% (4π) is assumed.**

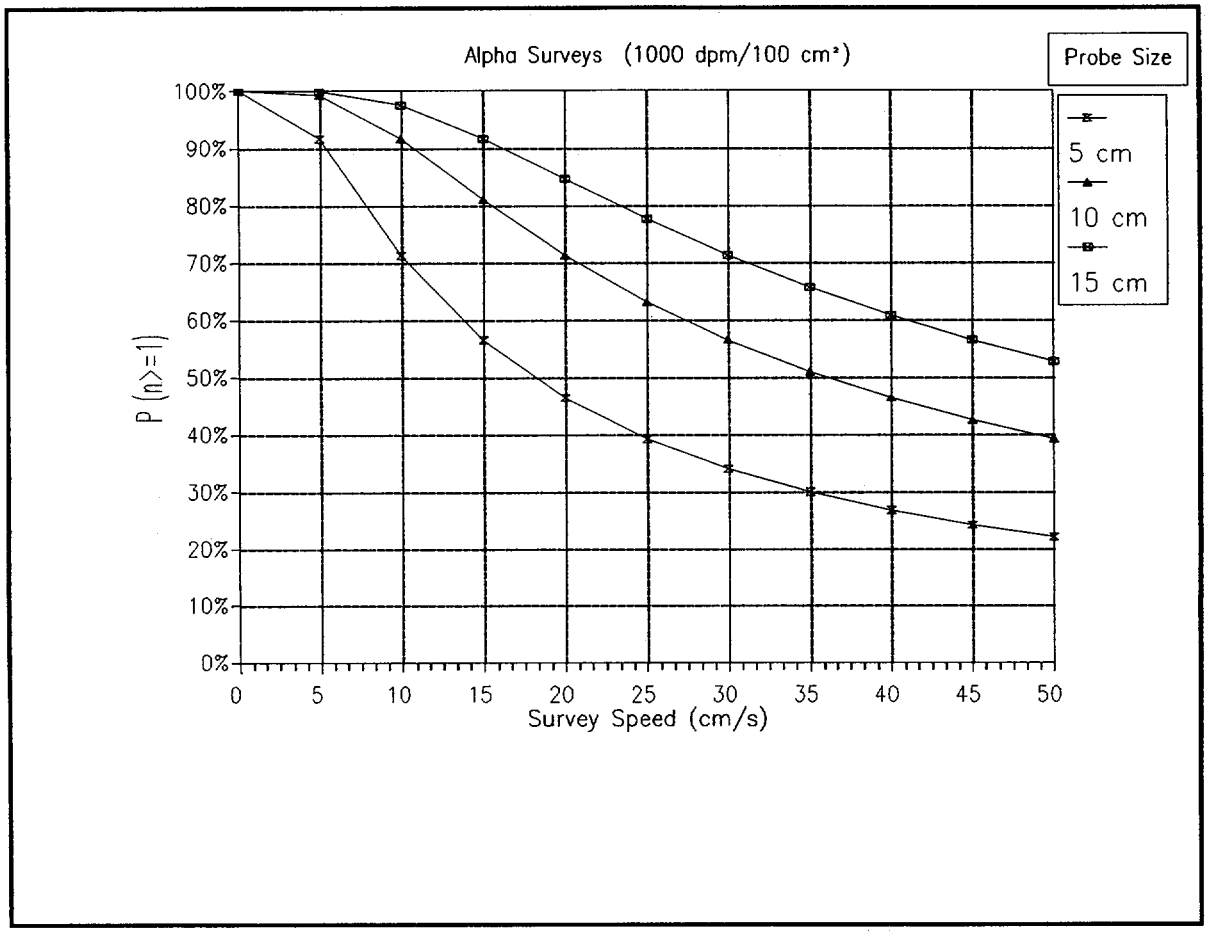

Figure J.2 **Probability (P) of getting one or more counts when passing over a 100 cm^2 area contaminated at 1,000 dpm/100 cm^2 alpha. The chart shows the probability versus scanning speed for three different probe sizes. The probe size denotes the dimensions of the probes which are in line with the direction of scanning. A detection efficiency of 15% (4π) is assumed.**

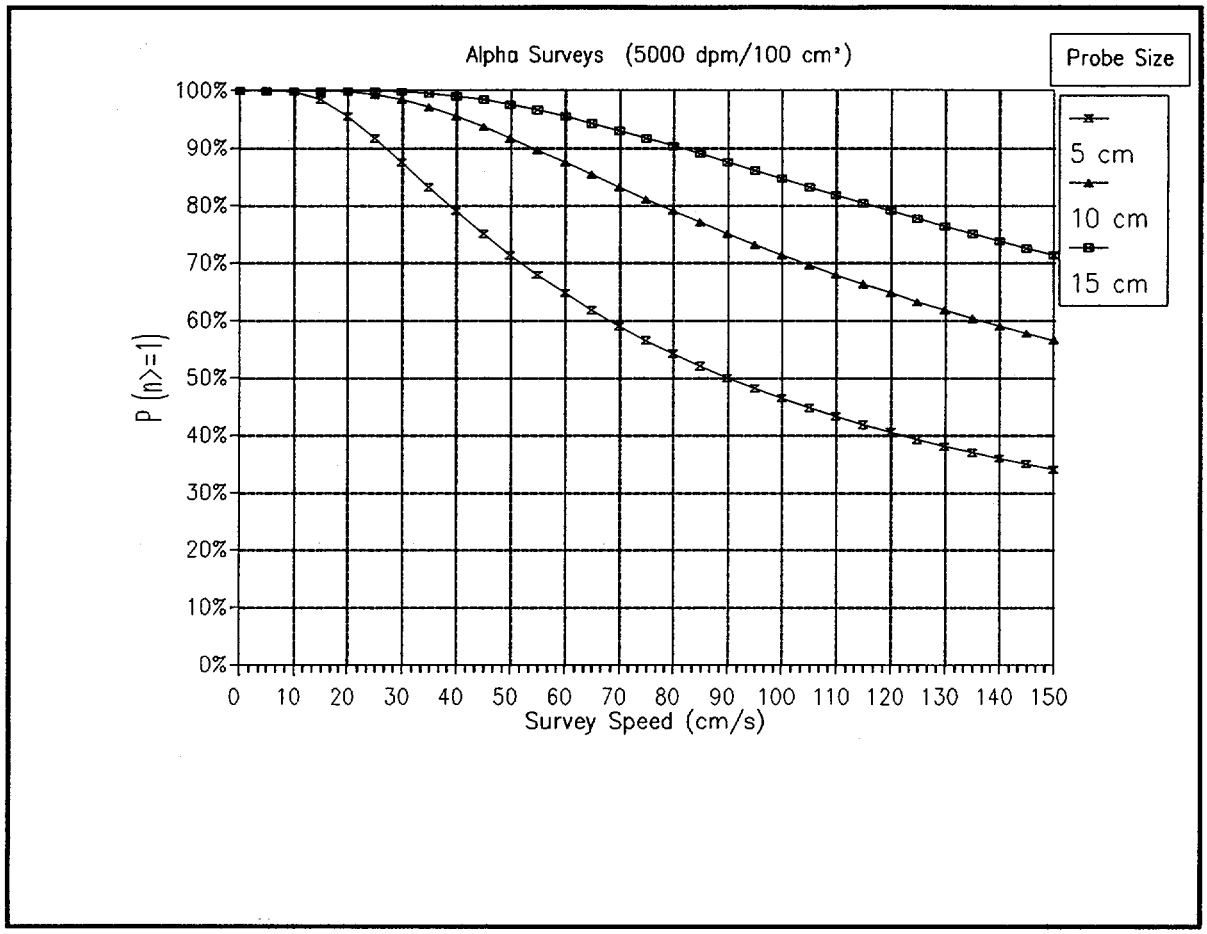

Figure J.3 **Probability (P) of getting one or more counts when passing over a 100 cm² area contaminated at 5,000 dpm/100 cm² alpha. The chart shows the probability versus scanning speed for three different probe sizes. The probe size denotes the dimensions of the probes which are in line with the direction of scanning. A detection efficiency of 15% (4π) is assumed.**

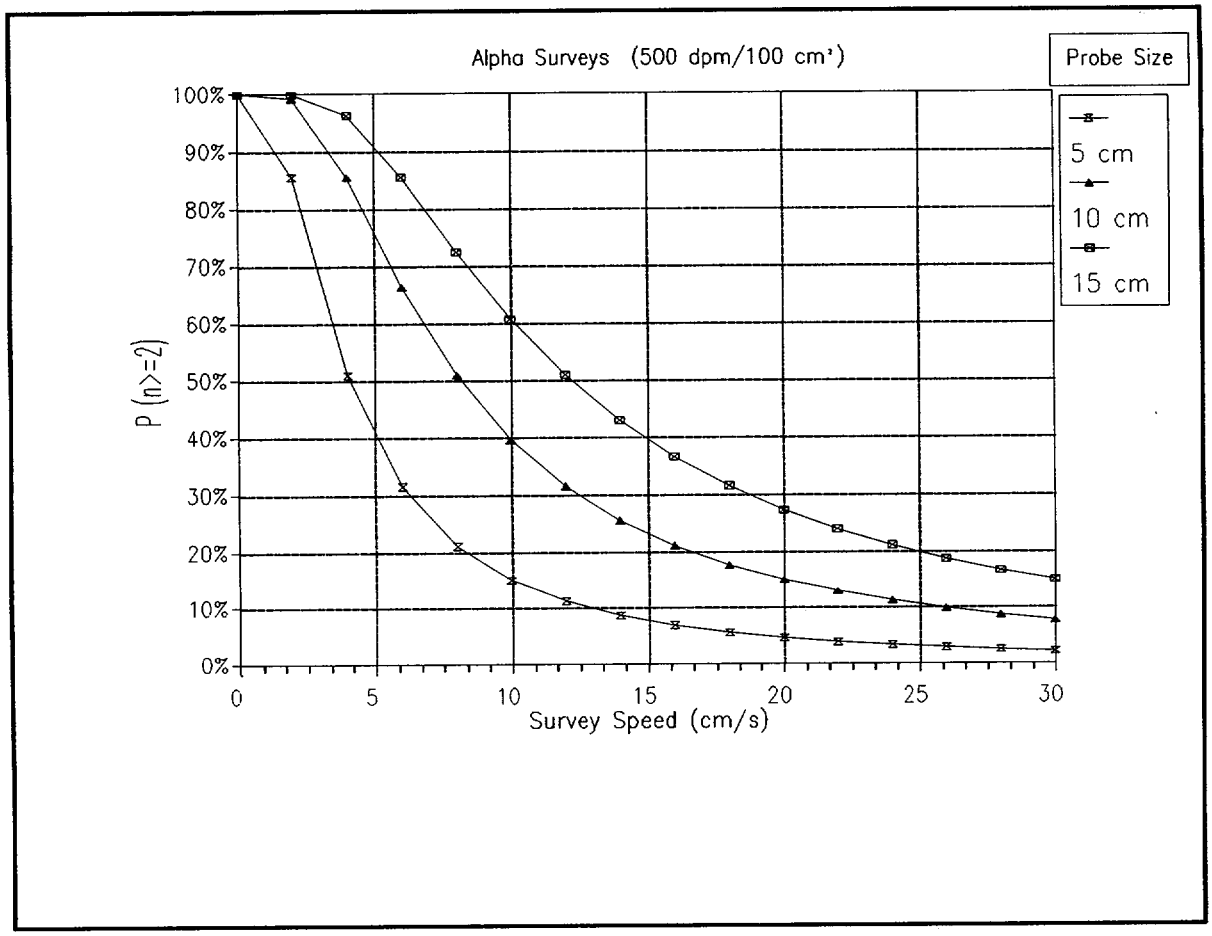

Figure J.4 **Probability (P) of getting two or more counts when passing over a 100 cm² area contaminated at 500 dpm/100 cm² alpha. The chart shows the probability versus scanning speed for three different probe sizes. The probe size denotes the dimensions of the probes which are in line with the direction of scanning. A detection efficiency of 15% (4π) is assumed.**

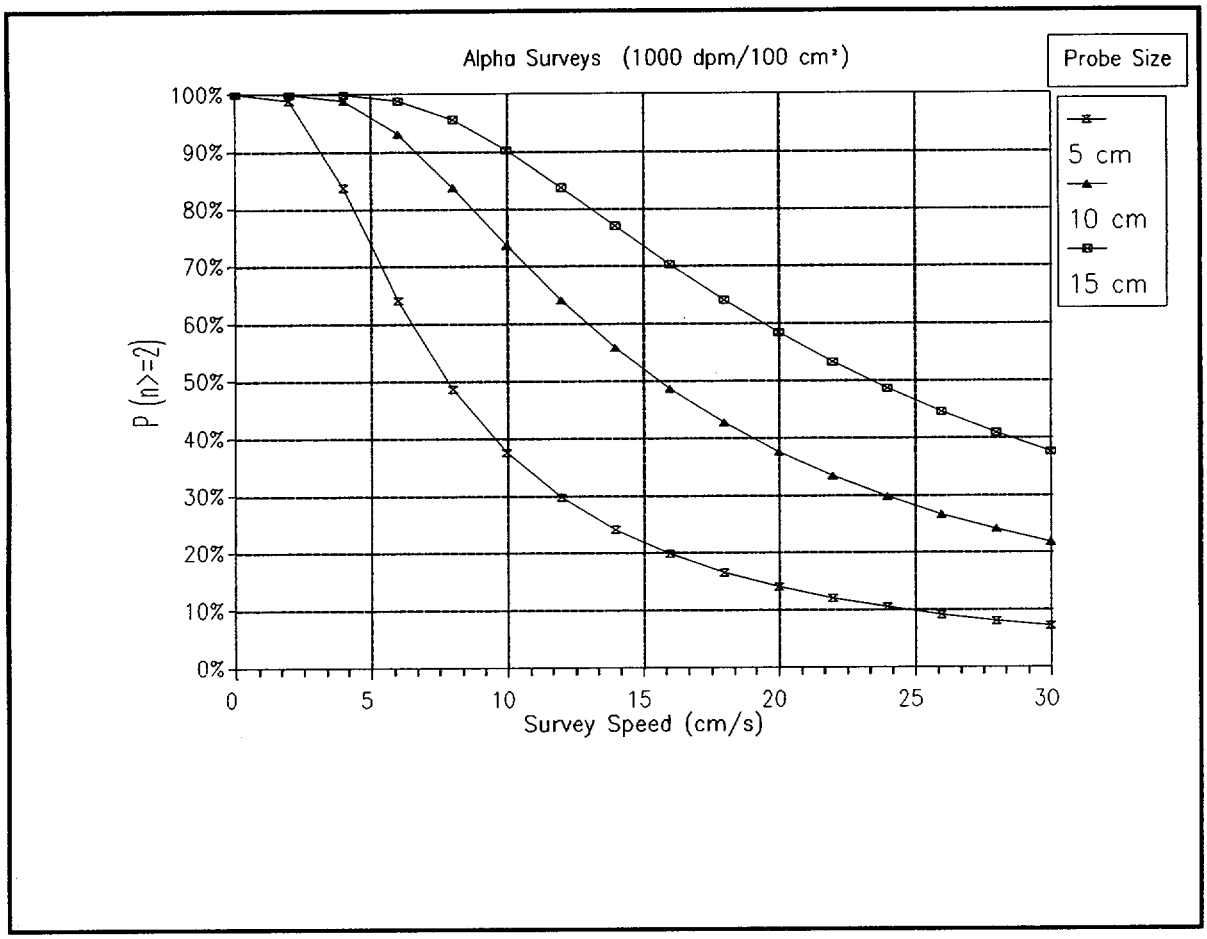

Figure J.5 **Probability (P) of getting two or more counts when passing over a 100 cm² area contaminated at 1,000 dpm/100 cm² alpha. The chart shows the probability versus scanning speed for three different probe sizes. The probe size denotes the dimensions of the probes which are in line with the direction of scanning. A detection efficiency of 15% (4π) is assumed.**

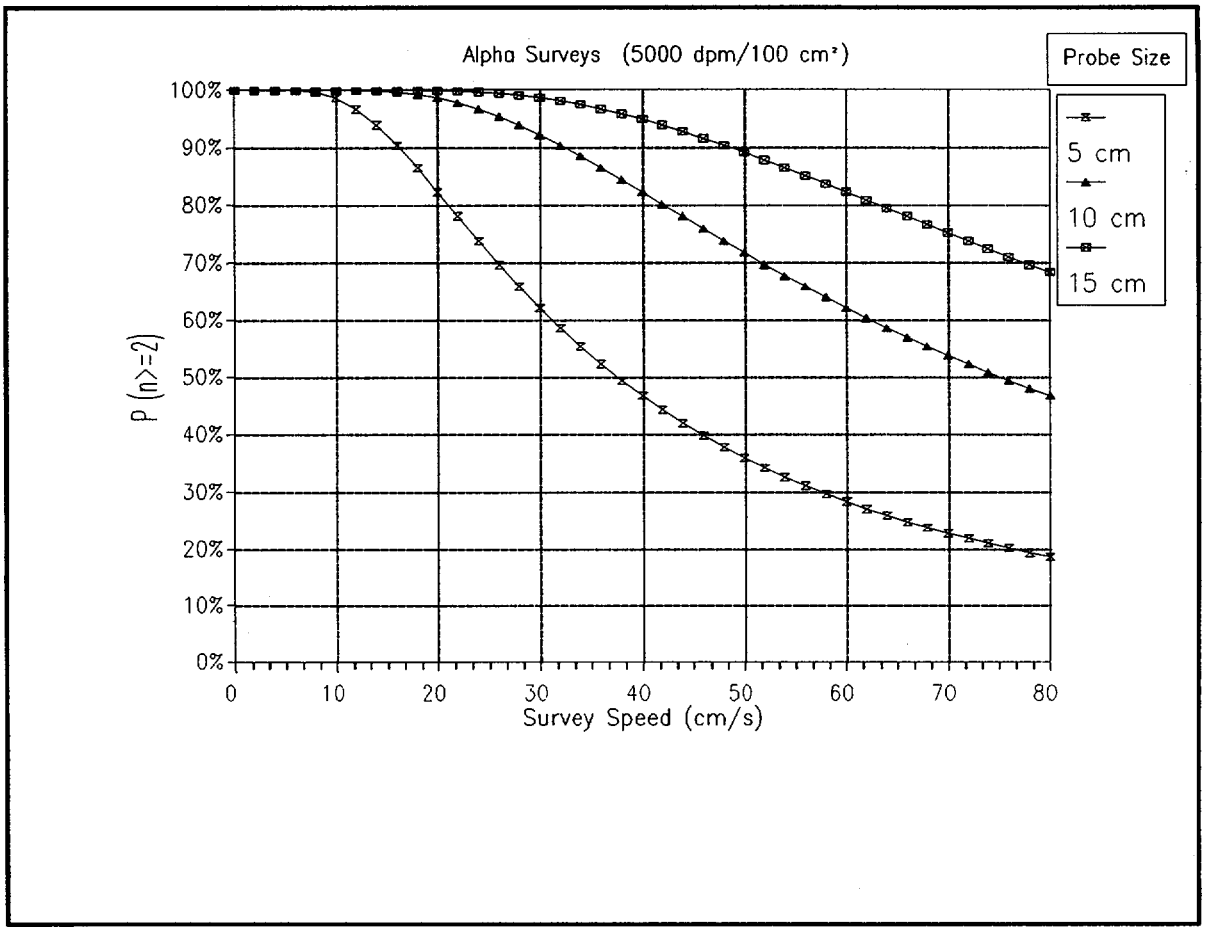

Figure J.6 **Probability (P) of getting two or more counts when passing over a 100 cm^2 area contaminated at 5,000 dpm/100 cm^2 alpha. The chart shows the probability versus scanning speed for three different probe sizes. The probe size denotes the dimensions of the probes which are in line with the direction of scanning. A detection efficiency of 15% (4π) is assumed.**

APPENDIX K

COMPARISON TABLES BETWEEN QUALITY ASSURANCE DOCUMENTS

The comparison tables in this appendix provide a reference for the MARSSIM user who may not be familiar with developing a QAPP based on EPA QA/R-5 (EPA 1994c). The tables relate the basic recommendations and requirements of EPA QA/R-5 and other quality assurance documents the reader may be more familiar with.

Each of the quality assurance documents compared in these tables was developed for a specific industry and scope. For this reason, there is not a direct comparison from one document to another. Rather, the tables are designed to show similarities between different quality assurance documents. In addition, there are topics specific to certain quality assurance documents that do not have a counterpart in these comparison tables.

If there is no section listed as being comparable with a section of EPA QA/R-5, this does not necessarily mean that the topic is not covered by the quality assurance document. In some cases the topic may have been divided up into several subtopics that are distributed between other sections of the particular document.

This appendix is not meant to provide a thorough cross-reference between different quality assurance documents. The purpose of these comparison tables is to demonstrate how the content of QAPPs might be arranged differently and show a user the location of important information concerning radiation surveys and site investigations. This might occur if the QAPP is developed using guidance the reviewer is unfamiliar with.

EPA QA/R-5 is compared with five quality assurance documents in the following tables:

- EPA QAMS-005/80 (EPA 1980d)
- ASME NQA-1 (ASME 1989)
- DOE Order 5700.6c (DOE 1991c)
- MIL-Q-9858A (DOD 1963)
- ISO 9000 (ISO 1987)

Table K.1 Comparison of EPA QA/R-5 and EPA QAMS-005/80

EPA QA/R-5 Elements		EPA QAMS-005/80	
A1	Title and Approval Sheet	1.0	Title Page with Provision for Approval Signatures
A2	Table of Contents	2.0	Table of Contents
A3	Distribution List		
A4	Project/Task Organization	4.0	Project Organization and Responsibility
A5	Problem Definition/Background	3.0	Project Description
A6	Project/Task Description	3.0	Project Description
A7	Quality Objectives and Criteria for Measurement Data	5.0	Quality Assurance Objectives for Measurement Data
A8	Project Narrative		
A9	Special Training Requirements/Certification		
A10	Documentation and Records		
B1	Sampling Process Design	6.0	Sampling Procedures
B2	Sampling Methods Requirements	6.0	Sampling Procedures
B3	Sample Handling and Custody Requirements	7.0	Sample Custody
B4	Analytical Methods Requirements	9.0	Analytical Methods
B5	Quality Control Requirements	11.0	Internal Quality Control Checks and Frequency
B6	Instrument/Equipment Testing, Inspection, and Maintenance Requirements	13.0	Preventive Maintenance Procedures and Schedules
B7	Instrument Calibration and Frequency	8.0	Calibration Procedures and Frequency
B8	Inspection/Acceptance Requirements for Supplies and Consumables		
B9	Data Acquisition Requirements		
B10	Data Quality Management		
C1	Assessments and Response Actions	12.0 15.0	Assessment and Response Actions Corrective Actions
C2	Reports to Management	16.0	Quality Assurance Reports to Management
D1	Data Review, Validation, and Verification Requirements	10.0	Data Reduction, Validation, and Reporting
D2	Validation and Verification Methods	10.0	Data Reduction, Validation, and Reporting
D3	Reconciliation with User Requirements		

Table K.2 Comparison of EPA QA/R-5 and ASME NQA-1

EPA QA/R-5 Elements		ASME NQA-1 Elements	
A1	Title and Approval Sheet		
A2	Table of Contents		
A3	Distribution List		
A4	Project/Task Organization	1.	Organization
A5	Problem Definition/Background		
A6	Project/Task Description	3.	Design Control
A7	Quality Objectives and Criteria for Measurement Data	2.	Quality Assurance Program
A8	Project Narrative	8.	Identification and Control of Items
A9	Special Training Requirements/Certification		
A10	Documentation and Records	4. 6.	Procurement Document Control Document Control
B1	Sampling Process Design	3.	Design Control
B2	Sampling Methods Requirements	5.	Instructions, Procedures, and Drawings
B3	Sample Handling and Custody Requirements	13.	Handling, Storage, and Shipping
B4	Analytical Methods Requirements	5.	Instructions, Procedures, and Drawings
B5	Quality Control Requirements	9. 11.	Control of Processes Test Control
B6	Instrument/Equipment Testing, Inspection, and Maintenance Requirements	10. 12.	Inspection Control of Measuring and Test Equipment
B7	Instrument Calibration and Frequency	14.	Inspection, Test, and Operating Status
B8	Inspection/Acceptance Requirements for Supplies and Consumables	7. 8.	Control of Purchased Items and Services Identification and Control of Items
B9	Data Acquisition Requirements		
B10	Data Quality Management		
C1	Assessments and Response Actions	15. 16. 18.	Control of Nonconforming Items Corrective Action Audits
C2	Reports to Management	17.	Quality Assurance Records
D1	Data Review, Validation, and Verification Requirements		
D2	Validation and Verification Methods		
D3	Reconciliation with User Requirements		

Table K.3 Comparison of EPA QA/R-5 and DOE Order 5700.6c

EPA QA/R-5 Elements		DOE Order 5700.6C Elements	
A1	Title and Approval Sheet		
A2	Table of Contents		
A3	Distribution List		
A4	Project/Task Organization	2	Personnel Training and Qualification
A5	Problem Definition/Background	1	Program
A6	Project/Task Description		
A7	Quality Objectives and Criteria for Measurement Data	1	Program
A8	Project Narrative		
A9	Special Training Requirements/Certification	2	Personnel Training and Qualification
A10	Documentation and Records	4	Documents and Records
B1	Sampling Process Design	6	Design
B2	Sampling Methods Requirements	5	Work Processes
B3	Sample Handling and Custody Requirements		
B4	Analytical Methods Requirements	5	Work Processes
B5	Quality Control Requirements		
B6	Instrument/Equipment Testing, Inspection, and Maintenance Requirements	8	Inspection and Acceptance Testing
B7	Instrument Calibration and Frequency		
B8	Inspection/Acceptance Requirements for Supplies and Consumables	7 8	Procurement Inspection and Acceptance Testing
B9	Data Acquisition Requirements		
B10	Data Quality Management		
C1	Assessments and Response Actions	10	Independent Assessment
C2	Reports to Management	9	Management Assessment
D1	Data Review, Validation, and Verification Requirements		
D2	Validation and Verification Methods		
D3	Reconciliation with User Requirements	3	Quality Improvement

Table K.4 Comparison of EPA QA/R-5 and MIL-Q-9858A

EPA QA/R-5 Elements		MIL-Q-9858A Elements	
A1	Title and Approval Sheet		
A2	Table of Contents		
A3	Distribution List		
A4	Project/Task Organization	3.1	Organization
A5	Problem Definition/Background		
A6	Project/Task Description		
A7	Quality Objectives and Criteria for Measurement Data	3.2	Initial Quality Planning
A8	Project Narrative		
A9	Special Training Requirements/Certification		
A10	Documentation and Records	3.4 4.1	Records Drawings, Documentation, and Changes
B1	Sampling Process Design		
B2	Sampling Methods Requirements	3.3	Work Instructions
B3	Sample Handling and Custody Requirements	6.4	Handling, Storage, and Delivery
B4	Analytical Methods Requirements	3.3	Work Instructions
B5	Quality Control Requirements	6.7	Identification of Inspection Status
B6	Instrument/Equipment Testing, Inspection, and Maintenance Requirements	4.2	Measuring and Test Equipment
B7	Instrument Calibration and Frequency	4.2	Measuring and Test Equipment
B8	Inspection/Acceptance Requirements for Supplies and Consumables	5.0 6.1	Control of Purchases Materials and Material Control
B9	Data Acquisition Requirements		
B10	Data Quality Management	3.4	Records
C1	Assessments and Response Actions	3.5 6.5	Corrective Action Nonconforming Material
C2	Reports to Management	3.6	Costs Related to Quality
D1	Data Review, Validation, and Verification Requirements		
D2	Validation and Verification Methods	6.6	Statistical Quality Control
D3	Reconciliation with User Requirements		
		6.2	Production Processing and Fabrication
		6.3	Completed Item Inspection and Test

Table K.5 Comparison of EPA QA/R-5 and ISO 9000

EPA QA/R-5 Elements		ISO 9000 Elements	
A1	Title and Approval Sheet		
A2	Table of Contents		
A3	Distribution List		
A4	Project/Task Organization	4	Management Responsibility
A5	Problem Definition/Background		
A6	Project/Task Description		
A7	Quality Objectives and Criteria for Measurement Data	5 5.2	Quality System Principles Structure of the Quality System
A8	Project Narrative		
A9	Special Training Requirements/Certification		
A10	Documentation and Records		
B1	Sampling Process Design	8	Quality in Specification and Design
B2	Sampling Methods Requirements	10	Quality in Production
B3	Sample Handling and Custody Requirements	16	Handling and Post Production Functions
B4	Analytical Methods Requirements	10	Quality in Production
B5	Quality Control Requirements	11	Control of Production
B6	Instrument/Equipment Testing, Inspection, and Maintenance Requirements	13	Control of Measuring and Test Equipment
B7	Instrument Calibration and Frequency		
B8	Inspection/Acceptance Requirements for Supplies and Consumables	9 11.2	Quality in Procurement Material Control and Traceability
B9	Data Acquisition Requirements		
B10	Data Quality Management		
C1	Assessments and Response Actions	5.4 14 15	Auditing the Quality System Nonconformity Corrective Action
C2	Reports to Management	5.3 6	Documentation of the Quality System Economics—Quality Related Costs
D1	Data Review, Validation, and Verification Requirements	11.7	Control of Verification Status
D2	Validation and Verification Methods	12	Verification Status
D3	Reconciliation with User Requirements		
		7	Quality in Marketing

APPENDIX L

REGIONAL RADIATION PROGRAM MANAGERS

The following is a directory list of regional program managers in Federal agencies who administer radiation control activities and have responsibility for certain radiation protection activities. The telephone numbers and addresses in this appendix are subject to change without notice. A more complete directory list of professional personnel in state and local government agencies is available from the Conference of Radiation Control Program Directors, Inc. (CRCPD). This directory is updated and distributed yearly. To obtain a copy of this annual publication please write to:

CRCPD
Attn: Ellen Steinberg
205 Capital Avenue
Frankfort, KY 40601
(502) 227-4543

L.1 Department of Energy (DOE)

DOE Home Page — http://www.doe.gov

Oak Ridge Operations Office
ORO Public Affairs Office
Post Office Box 2001
Oak Ridge, Tennessee 37831
Telephone: (865) 576-0885
(865) 576-9262
http://www.oakridge.doe.gov/

Savannah River Operations Office
Department of Energy
Post Office Box A
Aiken, South Carolina 29802
Telephone: (803) 725-2889
(803) 725-3966
http://www.srs.gov/

Albuquerque Operations Office
Department of Energy
Post Office Box 5400
Albuquerque, New Mexico 87185-5400
Telephone: (505) 845-6202
(505) 845-5581
http://www.doeal.gov/

Chicago Operations Office
Department of Energy
9800 South Cass Avenue
Argonne, Illinois 60439
Telephone: (630) 252-2013
http://www.ch.doe.gov/

Idaho Operations Office
Department of Energy
Post Office Box 1625
Idaho Falls, Idaho 83415
Telephone: (208) 526-0833
http://www.id.doe.gov/doeid/index.html

Oakland Operations Office
Department of Energy
1301 Clay Street, 180 N
Oakland, California 94612
Telephone: (510) 637-1762
(510) 637-1814
http://www.oak.doe.gov/

Richland Operations Office
Department of Energy
Post Office Box 550, A7-75
Richland, Washington 99352
Telephone: (509) 376-7501
(509) 376-6506
http://www.hanford.gov/

Nevada Operations Office
Department of Energy
PO Box 98518
Las Vegas, NV 89193-8518
Telephone: (702) 295-3521
http://www.nv.doe.gov/

L.2 Environmental Protection Agency (EPA)

EPA Home Page — http://www.epa.gov

Region 1	(CT, MA, ME, NH, RI, VT) U.S. Environmental Protection Agency Region 1 1 Congress Street Boston, Massachusetts 02114-2023	Telephone: (617) 723-8928 http://www.epa.gov/region01/
Region 2	(NJ, NY, PR, VI) U.S. Environmental Protection Agency Region 2 290 Broadway New York, New York 10007-1866	Telephone: (212) 637-3000 http://www.epa.gov/Region2/
Region 3	(DC, DE, MD, PA, VA, WV) U.S. Environmental Protection Agency Region 3 1650 Arch Street Philadelphia, Pennsylvania 19103-2029	Telephone: (800) 438-2474 (215) 814-5000 http://www.epa.gov/region03/
Region 4	(AL, FL, GA, KY, MS, NC, SC, TN) U.S. Environmental Protection Agency Region 4 Atlanta Federal Center 61 Forsyth Street, SW Atlanta, Georgia 30303-3104	Telephone: (404) 562-9900 (800) 241-1754 http://www.epa.gov/region4/reg4.html
Region 5	(IL, IN, MI, MN, OH, WI) U.S. Environmental Protection Agency Region 5 77 West Jackson Boulevard (AT-18J) Chicago, Illinois 60604-3507	Telephone: (312) 353-2000 (800) 621-8431* http://www.epa.gov/Region5/

* 800 number is only available within the specified EPA Region

Region 6	(AR, LA, NM, OK, TX) U.S. Environmental Protection Agency Region 6 1445 Ross Avenue, Suite 1200 Dallas, Texas 75202-2733	Telephone: (214) 665-2200 (800) 887-6063* http://www.epa.gov/earth1r6/index.htm
Region 7	(IA, KS, MO, NE) U.S. Environmental Protection Agency Region 7 901 North 5th Street Kansas City, Kansas 66101	Telephone: (913) 551-7003 (800) 223-0425 http://www.epa.gov/rgytgrnj/
Region 8	(CO, MT, ND, SD, UT, WY) U.S. Environmental Protection Agency Region 8 999 18th Street, Suite 300 Denver, Colorado 80202-2466	Telephone:(303) 312-6312 (800) 227-8917* http://www.epa.gov/unix0008/
Region 9	(AZ, CA, HI, NV, American Samoa, and Guam) U.S. Environmental Protection Agency Region 75 Hawthorne Street 9 San Francisco, California 94105	Telephone: (415) 744-1702 (415) 744-1305 http://www.epa.gov/region09/
Region 10	(AK, ID, OR, WA) U.S. Environmental Protection Agency Region 10 1200 Sixth Avenue Seattle, Washington 98101	Telephone: (206) 553-1200 (800) 424-4372* http://www.epa.gov/r10earth/

* 800 number is only available within the specified EPA Region

L.3 Nuclear Regulatory Commission (NRC)

NRC Home Page http://www.nrc.gov

Region I (CT, DC, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT)
Administrator
U.S. Nuclear Regulatory Commission
475 Allendale Road
King of Prussia, Pennsylvania 19406-1415
Telephone: (610) 337-5299
(610) 337-5000

Region II (AL, FL, GA, KY, MS, NC, PR, SC, TN, VA, VI, WV, Panama Canal)
Administrator
U.S. Nuclear Regulatory Commission
Atlanta Federal Center, 23 T85
61 Forsyth Street, SW
Atlanta, Georgia 30303-8931
Telephone: (404) 331-4400

Region III (IA, IL, IN, MI, MN, MO, OH, WI)
Administrator
U.S. Nuclear Regulatory Commission
801 Warrenville Road
Lisle, Illinois 60532-4351
Telephone: (630) 829-9657
(630) 829-9500

Region IV (AR, CO, ID, KS, LA, MT, NE, ND, NM, OK, SD, TX, UT, WY, AK, AZ, CA, HI, NV, OR, WA, Pacific Trust Territories)
Administrator
U.S. Nuclear Regulatory Commission
611 Ryan Plaza Drive, Suite 400
Arlington, Texas 76011-8064
Telephone: (817) 860-8225
(817) 860-8100

L.4 Department of the Army

The following is a list of key personnel within the Department of the Army who administer radiation control activities and have responsibilities for certain radiation protection activities.

Deputy for Environmental Safety & Occupational Health
Office of the Assistant Secretary of the Army
(Installations, Logistics, & Environment)
110 Army Pentagon
Washington, DC 20310-0110
Telephone: (703) 695-7824

Director of Army Radiation Safety
Army Safety Office
DACS-SF
Chief of Staff
200 Army Pentagon
Washington, DC 20310-0200
Telephone: (703) 695-7291

Radiological Hygiene Consultant
Office of The Surgeon General
Walter Reed Army Medical Center
Attn: MCHL-HP
Washington, DC 20307-5001
Telephone: (301) 427-5107

L.5 Department of the Navy

The following is a list of key personnel within the Department of the Navy who administer radiation control activities and have responsibilities for certain radiation protection activities.

Navy Radiation Safety Committee
Chief of Naval Operations (N455)
2211 Jefferson Davis Highway
Crystal Plaza #5, Room 678
Arlington, VA 22244-5108
Telephone: (703) 602-2582

Commander (SEA-07R)
Radiological Controls Program
Naval Sea Systems Command
2531 Jefferson Davis Highway
Arlington, VA 22242-5160
Telephone: (703) 602-1252

Officer in Charge
Radiological Affairs Support Office
P.O. Drawer 260
Yorktown, VA 23691-0260
Telephone: (757) 887-4692

L.6 Department of the Air Force

The following is a list of key personnel within the Department of the Air Force who administer radiation control activities and have responsibilities for certain radiation protection activities.

Chief, Materials Licensing
USAF Radioisotope Committee
AFMOA/SGOR
110 Luke Avenue, Room 405
Bolling AFB, DC 20332-7050

Telephone: (202) 767-4313

Chief, Consultant Branch
Radiation Services Division, Armstrong Laboratory
IERA/SDRH
2402 E Street
Brooks AFB, TX 78235-5114

Telephone: (210) 536-3486

APPENDIX M

SAMPLING METHODS: A LIST OF SOURCES

M.1 Introduction

Planning activities associated with field survey work include developing new and compiling or adopting existing sampling methods. The following listing includes documents that represent examples for the types of information one encounters when searching for sampling methods. This listing initially presents references that appear with brief annotations that characterize the information found in each document.

Journal articles and books may list references that lead to still other types of useful information. Depending on survey needs, media being sampled, or site-specific requirements, one may follow these references to resources that describe other types of methods found in original papers or documents that appeared even as specific sampling techniques were first introduced.

The present listing is not exhaustive. Other titles or resources for sampling methods are available through online literature databases; Federal, State, and university libraries; the internet; and other sources.

M.2 List of Sources

Department of Energy (DOE). 1987. *The Environmental Survey Manual*. DOE/EH-0053, Vol. 1 of 4. DOE, Office of the Assistant Secretary for Environment, Safety, and Health, Office of Environmental Audit, Washington, D.C.

- *General Description of Document*: Size: Approximately 188 pages (single sided)—This is the first of a four volume set that amounts to over 4 ins. (total thickness) of documentation related to environmental surveys. The first volume represents the main document, with the remaining three volumes contain eleven appendices.

- *Key Features of This Document*: Unlike a number of other references listed here, this document *does* include information related to radionuclides and considers biota (animal, plant, and related sample types). Flow charts, checklists, planning diagrams, and figures help the reader to visualize a number of topics described in the text of all four volumes. Section 2 of this volume entertains topics related to a survey team's activities and survey reports. Section 3 considers the use of existing data, followed by technical checklists in Section 4 and health and safety issues described in Section 5.

A quick review of this first volume reveals a limited amount of depth to the information presented. There is little descriptive *How To Sample* information given here. However, as an overview, the document is quite comprehensive and this may encourage a survey team to consider obtaining additional information relevant to a particular project need.

Department of Energy (DOE). 1987. *The Environmental Survey Manual: Appendices A, B, and C.* DOE/EH-0053, Vol. 2 of 4. DOE, Office of the Assistant Secretary for Environment, Safety, and Health, Office of Environmental Audit, Washington, D.C.

- *General Description of Document*: Size: Approximately 188 pages (double sided)—This second volume contains three of eleven appendices.

- *Key Features of This Document*: The appendices include: A) Criteria for Data Evaluation, B) Checklists and Lines of Inquiry, and C) Health and Safety Plan for On-Site Survey Activities.

Department of Energy (DOE). 1987. *The Environmental Survey Manual: Appendix D.* DOE/EH-0053, Vol. 3 of 4. DOE, Office of the Assistant Secretary for Environment, Safety, and Health, Office of Environmental Audit, Washington, D.C.

- *General Description of Document*: Size: Approximately 438 pages (double sided)—This single volume is the largest part of the four part set and contains only one appendix: Appendix D - Analytical Methods.

- *Key Features of This Document*: The topics presented here have little to do with sample collection and are mostly concerned with the types of compounds or constituents within a sample. A radiological section covers a number of radionuclides that one may encounter in a number of sample matrices—including in water, air, soil, and sediments. Again, this is an appendix dedicated to sample analysis.

Department of Energy (DOE). 1987. *The Environmental Survey Manual: Appendices E, F, G, H, I, J, and K.* DOE/EH-0053, Vol. 4 of 4. DOE, Office of the Assistant Secretary for Environment, Safety, and Health, Office of Environmental Audit, Washington, D.C.

- *General Description of Document*: Size: Approximately 312 pages (double sided)—This fourth and final volume includes seven appendices.

- *Key Features of This Document*: Appendix E is entitled *Field Sampling Protocols and Guidance*—which offers a number of site scenarios to describe an approach to sampling under varied conditions. Each scenario is followed by a set of sampling procedures appropriate for a particular sample matrix. This appendix is 216 pages in length making this the largest part of Volume 4. Diagrams are included to illustrate scenarios and the appearance of sampling equipment.

  The remaining appendices cover: F) guidelines for preparation of quality assurance plans, G) decontamination guidance, H) data management and analysis, I) sample and document management guidance, J) health and safety guidance for sampling and analysis teams, and K) documents for sampling and analysis program.

Department of Energy (DOE). 1991. *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*. DOE/EH-0173T, DOE, Assistant Secretary for Environment, Safety, and Health, Washington, D.C. (DE91-013607)

- *General Description of Document*: Size: approximately 90 pages— This guide covers a number of topics related to radiation and environmental surveillance.

- *Key Features of This Document*: To accomplish environmental surveillance, various sample types—from biotic (animal and plant) to abiotic (air, water, soil, *etc.*)—are considered in Chapter 5 (title: Environmental Surveillance). The basis for taking certain samples appears along with information on sample location and frequency. A brief statement on sampling methods completes each section but procedures or techniques are not given in detail. References to other guidance documents on sampling are cited. The reader is directed to other sources to obtain additional regulatory information or descriptions of specific procedures.

  Chapter 6 provides information on laboratory procedures. Other chapters cover: liquid effluent monitoring, airborne effluent monitoring, meteorological monitoring, data analysis and statistical treatment, dose calculations, records and reports, quality assurance (QA), and reports.

Department of Energy (DOE). 1994. *Decommissioning Handbook.* DOE/EM-0142P. DOE, Office of Environmental Restoration, Germantown, MD

- *General Description of Document*: Size: Approximately 312 pages—The manual is essentially written for those involved in decommissioning a nuclear power facility. While not specifically focused on radiation sampling methods, this document may play a role in

identifying activities or sampling needs related to survey work before or during remediation at some Federal facilities.

- *Key Features of This Document*: Chapter 6 presents information on final project configuration based on planning and as such speaks of site boundaries. Chapter 7 presents topics related to characterization including on-site measurements.

  This document includes discussion and illustrations of robotic devices used in sampling operations. Perhaps only appropriate in extreme situations, the use of a robot for obtaining a sample may apply where radiation levels are high, dust or air quality pose problems, or where technical staff cannot physically reach a sample location due to structural limitations.

Environmental Protection Agency (EPA). 1980. *Samplers and Sampling Procedures for Hazardous Waste Streams*. EPA-600/2-80-018, EPA, Municipal Environmental Research Laboratory, Cincinnati, OH.

- *General Description of Document*: Size: 67 pages—the procedures listed here cover different types of media and include helpful diagrams of sampling devices.

- *Key Features of This Document*: While not specifically geared to radioactive samples, this short manual outlines and presents information in a logical sequence—starting with descriptions of sampling devices, followed by discussion of selecting an appropriate device for various media (including samples taken from various sources; *e.g.*, drum, barrel, waste pile), container types, labels, seals, use of a log book, chain of custody, sample receipt and logging, preservation and storage of samples, and references. The document includes five appendices, covering development of the composite liquid waste sampler, parts for constructing the sampler, checklist of items required in the field for sampling hazardous waste, random sampling, and systematic errors in using the composite liquid waste sampler.

Environmental Protection Agency (EPA). 1982. *Test Methods For Evaluating Solid Waste, Physical / Chemical Methods, 2nd Edition.* EPA, Office of Solid Waste, Washington, D.C. (PB87-120291)

- *General Description of Document*: Size: Approximately 375 pages—composed of chapters and methods that update the first edition of this volume.

- *Key Features of This Document*: Chapter 1 of this manual pulls together information from the first three chapters of the first edition. This includes a Sampling Methodology section that addresses statistics, sampling strategies and examples, implementing a sampling plan, plus tables and figures of sampling devices, *etc.* The main focus is on solid waste including metals and organics. Methods are described with the same format as indicated above in reference 1. As above, the methods include some information relevant to the field component of sampling work, but the remainder of each method essentially is most useful to laboratory personnel.

Environmental Protection Agency (EPA). 1982. *Handbook for Sampling and Sample Preservation of Water and Wastewater.* EPA-600/4-82-029, EPA, Environmental Monitoring and Support Laboratory, Cincinnati, OH. (PB83-124503)

- *General Description of Document*: Size: Approximately 500 pages—composed of information specifically focused on sample collection and preservation. While the document concerns only water sampling, this volume is comprehensive and even includes a chapter on *Sampling Radioactive Materials.*

- *Key Features of This Document*: The handbook is geared to address sampling issues. The scope of the document covers all types or sources of water, including: municipal, industrial, surface, agricultural, ground, and drinking waters. Types of samples are defined and discussed, including grab and composite samples. Diagrams, tables, and forms are provided to illustrate key points raised in the text. Statistical methods and related tables are provided. Each topic is accompanied by references. The chapter on radioactive samples is brief but touches on: background, radioactive decay, detection capability, frequency of sampling, sampling location, sample volume, containers, filtration, preservation, general procedures, radiation safety, and references.

Environmental Protection Agency (EPA). 1984. *Soil Sampling Quality Assurance User's Guide.* EPA 600/4-84-043, EPA, Environmental Monitoring Systems Laboratory, Office of Research and Development, Las Vegas, NV.

- *General Description of Document*: Size: 102 pages—The introduction to this document starts with: "An adequate quality assurance/quality control (QA/QC) program requires the identification and quantification of all sources of error associated with each step of a monitoring program so that the resulting data will be of known quality. the components of error, or variance, include those associated with sampling, sample preparation, extraction, analysis, and residual error."

- *Key Features of This Document*: Because of potential inhomogeneity in soil samples, the authors state this QA/QC document is specifically concerned with soil sampling. The general outline of the document includes: objectives of QA/QC, statistics, exploratory studies, sample number and sample sites, sample collection, sample handling and documentation, analysis and interpretation of QA/QC data, and systems audits and training. References are provided followed by two appendices covering sample number precision and confidence plus tables for use in calculating confidence tolerance limits and judging validity of measurements.

  The sample collection chapter is very brief and does not specifically outline methods or types of equipment. This and the following chapter on sample handling and documentation mention relevant topics in light of QA/QC.

Environmental Protection Agency (EPA). 1986. *Engineering Support Branch Standard Operating Procedures and Quality Assurance Manual.* EPA, Region IV, Environmental Services Division, Athens, GA. (Sections 3 to 5 reviewed)

- *General Description of Document*: Size: approximately 90 pages (single sided)—The introduction states: "The objectives of this section are to present the Branch standard operating procedures for sample identification, sample control and chain of custody, maintenance of field records, and document control.

- *Key Features of This Document*: The basic format of the document is that of a compendium of standard operating procedures bound in one volume. Each Standard Operating Procedure (SOP) is several pages and is dedicated to a specific topic. A five page outline pertaining to sampling procedures presents a brief overview that is a relatively typical treatment of this topic. Sample preservation, for example, is summarized with five bullet points. The next section offers a three page listing of definitions covering grab, composite, split, duplicate, reference or control, and background samples, plus a very brief definition for sample aliquot.

  The document lacks figures but does include descriptive notes for equipment and methods related to taking samples of waste water, surface water (fresh and salt water), ground water, potable water supply, soil, samples from landfills and hazardous waste sites, followed by references. The last part of the guide include information on making flow measurements.

  The document does not appear to focus on radioactive materials, but as with other documents the information can in part be used in conjunction with obtaining radioactive samples.

Environmental Protection Agency (EPA). 1987. *A Compendium of Superfund Field Operations Methods*. EPA/540/P-87/001, EPA, Office of Emergency and Remedial Response, Washington, D.C.

- *General Description of Document*: Size: Approximately 375 pages—the size and title of this document is a clue to the comprehensive nature of this volume. In brief, the text of this document provides a potentially valuable resource to field workers involved with Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) surveys. While relatively complete—in that the document covers a broad range of topics—some readers may desire additional depth to the information provided here. Conversely, planners and field personnel might gain added insight by considering the broad range of topics included here before approaching the survey process.

- *Key Features of This Document*: Perhaps the best summary of this compendium is provided by a listing of sections, as follows: 1) Use of the Compendium, 2) Preparation of Project Description and Statement of Objectives, 3) Implementing Field Objectives, 4) Sample Control, Including Chain of Custody, 5) Laboratory Interface, 6) Sample Containers, Preservation, and Shipping, 7) Field Methods for Screening Hazardous Material, 8) Earth Sciences (*i.e.*, drilling, excavations, reconnaissance, geophysics, and ground water), 9) Earth Sciences Laboratory Procedures, 10) Surface Hydrology, 11) Meteorology and Air Quality, 12) Specialized Sampling Techniques (*e.g.*, wipes, human habitation sampling, TCDD, and container sampling), 14) Land Surveying, Aerial Photography, and Mapping, 15) Field Instrumentation (a comprehensive treatment including radiation monitors), 16) data handling, 17) Document Control, 18) Corrective Action, 19) QA Audit Procedures, and 20) QA Reporting.

  That this document serves objectives set forth by Superfund—and is not specifically focused on radionuclide sampling—in no way diminishes the importance of the compendium's complete overview of field sampling equipment and activities.

Environmental Protection Agency (EPA). 1989. *Test Methods For Evaluating Solid Waste Physical / Chemical Methods - Third Edition Proposed Update Package*. EPA, Office of Solid Waste, Washington, D.C. (PB89-148076)

- *General Description of Document*: Size Approximately 500 pages—composed of several updated chapters and 46 methods that are described by text and graphics. Only methods that are updated from 2nd Edition appear in this volume.

- *Key Features of This Document*: Chapters 1, 2, 4, and 7 describe QC, Choosing the Correct Procedure, Organic Analytes, and Regulatory Definitions, respectively. Of primary interest are the 46 methods that are described in what constitutes the bulk of this document. However, as is evident from some of the first methods listed for organics, sample collection techniques are only briefly touched on by a section of Chapter Four. This essentially makes the methods laboratory oriented protocols and the only reference to field methods appears in the text of a short chapter as opposed to part of each method. Some methods do list *Sample Collection, Preservation, and Handling* information with emphasis on use of containers, acidification or refrigeration, or a brief set of points to consider when preparing to go out to the field.

  Each method includes a method number and a title, plus the following information: 1) Scope and Application, 2) Summary of Method, 3) Interferences, 4) Apparatus and Materials, 5) Reagents, 6) Sample Collection, Preservation, and Handling, 7) Procedure, 8) QC, 9) Method Performance, and 10) References. Diagrams, flow charts, and tables follow the initial sequence of sections.

  The listing of methods include Method 9320 for Radium-228, Method 9310 for Gross Alpha & Gross Beta, and Method 9315 for Alpha-Emitting Radium Isotopes. These methods do not appear in the bound volume used for this review and thus no further comment is offered here.

Environmental Protection Agency (EPA). 1991. *Compendium of ERT Surface Water and Sediment Sampling Procedures*. OSWER Directive 9360.4-03, EPA, Office of Emergency and Remedial Response, Washington, D.C. (PB91-921274)

- *General Description of Document*: Size: 31 pages—this document includes three standard operating procedures (SOPs), the first of which is the same as the first SOP listed in the document described below.

- *Key Features of This Document*: The three SOPs included in this document include: 1) Sampling Equipment Decontamination, 2) Surface Water Sampling, and 3) Sediment Sampling. Each SOP is similar in content with sections that cover: scope, method summary, preservation, containers, equipment, apparatus, *etc.*

Environmental Protection Agency (EPA). 1991. *Compendium of ERT Ground water Sampling Procedures*. OSWER Directive 9360.4-06, EPA, Office of Emergency and Remedial Response, Washington, D.C. (PB91-921275)

- *General Description of Document*: Size: 71 pages—this document embodies eight standard operating procedures (SOPs) with a similar format as that described above.

- *Key Features of This Document*: The SOPs covered in this document include sampling equipment decontamination, ground water well sampling, soil gas samples, installing monitor wells, water level measurements, and other topics related to ground water and wells.

Environmental Protection Agency (EPA). 1991. *Compendium of ERT Soil Sampling and Surface Geophysics Procedures*. OSWER Directive 9360.4-02, EPA, Office of Emergency and Remedial Response, Washington, D.C. (PB91-921273)

- *General Description of Document*: Size: 39 pages—this document lists four standard operating procedures (SOPs) for soil sampling—with a similar format as that described above.

- *Key Features of This Document*: The SOPs covered in this document include sampling equipment decontamination, soil sampling, soil gas sampling, and soil sampling and surface geophysics. The SOP for soil sampling is five pages in length. This treatment essentially covers samples collected from the soil surface, to use of augers and tube samplers, a trier, split-spoon (barrel) sampler, and excavation techniques.

Environmental Protection Agency (EPA). 1991. *Environmental Compliance Branch Standard Operating Procedures and Quality Assurance Manual*. EPA, Region IV, Environmental Services Division, Athens, GA.

- *General Description of Document*: Size: Approximately 500 pages (single sided)—This document is presented with seven sections and eleven appendices. The main sections cover standard operating polices and procedures which relates to the Region IV laboratory's administrative functions to SOPs that are specifically focused on sampling activities.

- *Key Features of This Document*: Sections 3 and 4 are of primary importance when thinking of sample control, field record keeping, document control and sampling procedures. Section 4 on sampling procedures is descriptive—without diagrams or figures—and quite comprehensive in that this section touches on a multitude of topics not mentioned in a number of other guides, including: selection of parameters to be measured, holding time, cross contamination, and Data Quality Objectives (DQOs) (described as Level I to V). The sampling of soil, water, and air are covered in this section with many

of the subsections covering topics that are common to other documents reviewed here. A number of example forms are presented, including several that relate to State programs. Section 6 covers field analytical methods and Section 7 describes field physical measurements.

The appendices include helpful information relevant to sampling, including: A) sample containers, preservation, holding times, and permissible sample type, B) standard cleaning procedures, C) shipping procedures, D) standard field analytical methods, E) monitoring wells, F) pump operation procedures, G) air monitoring, H) wastewater field methods, I) saturation monitoring, and K) safety protocols.

Environmental Protection Agency (EPA). 1992. *Characterizing Heterogeneous Waste: Methods and Recommendations*. EPA/600/R92/033, EPA, Environmental Monitoring Systems Laboratory, Office of Research and Development, Las Vegas, NV. (PB92-216894)

- *General Description of Document*: Size: 144 pages—the focus of this document is on all types of waste materials that one might encounter. The base scenario appears to be one where a drum is encountered and the objective is to work to a point when the drum contents are understood. Because a drum may include more than one type of waste, this document provides a review of a wide variety of materials one might expect when surveying a site.

- *Key Features of This Document*: The table of contents reveals that the text attempts to provide a complete picture, from definitions of terms, to planning studies, QA/QC and data assessment, to sample acquisition, and steps that follow to the lab and what makes the characterization process a success. Radioactive waste materials, along with organics, solids, liquids, *etc.*, are covered, but in a relatively brief fashion. The model scenario of dealing with wastes in a drum is incorporated into a hypothetical example in an appendix.

Environmental Protection Agency (EPA). 1992. *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies*. EPA/600/R92/128, EPA, Office of Research and Development, Washington, DC. (PB92-220532)

- *General Description of Document*: Size: 174 pages—this document summarizes various statistical and geostatistical concepts and procedures pertaining to the design, implementation, and data interpretation of appropriate sampling designs.

- *Key Features of This Document*: This document focuses on applying the concept of the Data Life Cycle to soil sampling. The document describes statistical concepts that apply to soil sampling, including particulate sampling theory. Types of samples, numbers of samples, and size of samples as well as methods for sampling soils from conveyor belts and stockpiles are also discussed. A bibliography is provided.

APPENDIX N

Data Validation Using Data Descriptors

Data validation is often defined by six data descriptors:

1) reports to decision maker
2) documentation
3) data sources
4) analytical method and detection limit
5) data review
6) data quality indicators

The decision maker or reviewer examines the data, documentation, and reports for each of the six data descriptors to determine if performance is within the limits specified in the DQOs developed during survey planning. The data validation process should be conducted according to procedures documented in the QAPP.

N.1 Reports to Decision Maker

Data and documentation supplied to the decision maker should be evaluated for completeness and appropriateness and to determine if any changes were made to the survey plan during the course of work. The survey plan discusses the surveying, sampling, and analytical design and contains the QAPP and DQOs. The decision maker should receive all data as collected plus preliminary and final data reports. The final decision on qualifying or rejecting data will be made during the assessment of environmental data. All data, including qualified or rejected data, should be documented and recorded even if the data are not included in the final report.

Preliminary analytical data reports allow the decision maker to begin the assessment process as soon as the surveying effort has begun. These initial reports have three functions.

1) For scoping or characterization survey data, they allow the decision maker to begin to characterize the site on the basis of actual data. Radionuclides of interest will be identified and the variability in concentration can be estimated.

2) They allow potential measurement problems to be identified and the need for corrective action can be assessed.

3) Schedules are more likely to be met if the planning of subsequent survey activities can begin before the final data reports are produced.

N.2 Documentation

Three types of documentation should be assessed: (1) field operation records; (2) laboratory records; and (3) data handling records (EPA 1997a).

N.2.1 Field Operation Records

The information contained in these records documents overall field operations and generally consists of the following:

- *Field measurement records*. These records show that the proper measurement protocol was performed in the field. At a minimum, this documentation should include the names of the persons conducting the activity, measurement identification, measurement locations, measurement results, maps and diagrams, equipment and SOP used, and unusual observations. Bound field notebooks are generally used to record raw data and make references to prescribed procedures and changes in planned activities. Data recording forms might also be used. A document control system should be used for these records to control attributes such as formatting to include pre-numbered pages with date and signature lines.

- *Sample tracking records*. Sample tracking records (*e.g.*, chain-of-custody) document the progression of samples as they travel from the original sampling location to the laboratory and finally to disposal (see Section 7.7).

- *QC measurement records*. QC measurement records document the performance of QC measurements in the field. These records should include calibration and standards' traceability documentation that can be used to provide a reproducible reference point to which all similar measurements can be correlated. QC measurement records should contain information on the frequency, conditions, level of standards, and instrument calibration history.

- *Personnel files*. Personnel files record the names and training certificates of the staff collecting the data.

- *General field procedures*. General field procedures (*e.g.*, SOPs) record the procedures used in the field to collect data and outline potential areas of difficulty in performing measurements.

- *Deficiency and problem identification reports*. These reports document problems and deficiencies encountered as well as suggestions for process improvement.

- *Corrective action reports.* Corrective action reports show what methods were used in cases where general field practices or other standard procedures were violated and include the methods used to resolve noncompliance.

N.2.2 Laboratory Records

The following list describes some of the laboratory-specific records that should be compiled if available and appropriate:

- *Laboratory measurement results and sample data.* These records contain information on the sample analysis used to verify that prescribed analytical methods were followed. The overall number of samples, sample identification, sample measurement results, any deviations from the SOPs, time of day, and date should be included. Sample location information might also be provided.

- *Sample management records.* Sample management records should document sample receipt, handling and storage, and scheduling of analyses. The records will verify that sample tracking requirements were maintained, reflect any anomalies in the samples (*e.g.*, receipt of damaged samples), and note proper log-in of samples into the laboratory.

- *Test methods.* Unless analyses were performed exactly as prescribed by SOPs, this documentation will describe how the analyses were carried out in the laboratory. This documentation includes sample preparation and analysis, instrument standardization, detection and reporting limits, and method-specific QC requirements. Documentation demonstrating laboratory proficiency with each method used could also be a part of the data reporting package, particularly for subcontracted work.

- *QC measurement records.* These include the general QC records, such as initial demonstration of capability, instrument calibration, routine monitoring of analytical performance, calibration verification, *etc.*, considered in Section 7.3 for selecting a radioanalytical laboratory. Project-specific information from the QC checks such as blanks, spikes, calibration check samples, replicates, splits, and so on should be included in these reports to facilitate data quality analysis.

- *Deficiency and problem identification reports.* These reports document problems and deficiencies encountered as well as suggestions for process improvement.

- *Corrective action reports.* Corrective action reports show what methods were used in cases where general laboratory practices or other standard procedures were violated and include the methods used to resolve noncompliance. Corrective action procedures to replace samples violating the SOP also should be noted.

N.2.3 Data Handling Records

Data handling records document protocols used in data reduction, verification, and validation. Data reduction addresses data transformation operations such as converting raw data into reportable quantities and units, using significant figures, calculating measurement uncertainties, *etc.* The records document procedures for handling data corrections.

N.3 Data Sources

Data source assessment involves the evaluation and use of historical analytical data. Historical analytical data should be evaluated according to data quality indicators and not the source of the data (*e.g.*, analytical protocols may have changed significantly over time). Data quality indicators are qualitative and quantitative descriptors used in interpreting the degree of acceptability or utility of data. Historical data sources are addressed during the Historical Site Assessment, and are discussed in Section 3.4.1.

N.4 Analytical Method and Detection Limit

The selection of appropriate analytical methods based on detection limits is important to survey planning. The detection limit of the method directly affects the usability of the data because results near the detection limit have a greater possibility of false negatives and false positives. Results near the detection limit have increased measurement uncertainty. When the measurement uncertainty becomes large compared to the variability in the radionuclide concentration, it becomes more difficult to demonstrate compliance using the guidance provided in MARSSIM.

The decision maker compares detection limits (*i.e.*, minimum detectable concentrations; MDCs) with radionuclide-specific results to determine their effectiveness in relation to the DCGL. Assessment of preliminary data reports provides an opportunity to review the detection limits early and resolve any detection sensitivity problems. When a radionuclide is reported as not detected, the result can only be used with confidence if the MDCs reported are lower than the DCGL.

If the DCGL is less than or equal to the MDC, and the radionuclide is not detected, report the actual result of the analysis. Do not report data as "less than the detection limit." Even negative results and results with large uncertainties can be used in the statistical tests described in Chapter 8. Results reported as "<MDC" cannot be fully used and, for example, complicate even such simple analyses as calculating an average. When the MDC reported for a radionuclide is near the DCGL, the confidence in both identification and quantitation may be low. Information

concerning non-detects or detections at or near MDCs should be qualified according to the degree of acceptable uncertainty.

N.5 Data Review

Data review begins with an assessment of the quality of analytical results and is performed by a professional with knowledge of the analytical procedures. Only data that are reviewed according to a specified level or plan should be used in the quantitative site investigation. Any analytical errors, or limitations in the data that are identified by the review, should be noted. An explanation of data qualifiers should be included with the review report.

All data should receive some level of review. Data that have not been reviewed should be identified, because the lack of review increases the uncertainty in the data. Unreviewed data may lead to Type I and Type II decision errors, and may also contain transcription errors and calculation errors. Data may be used in the preliminary assessment before review, but should be reviewed at a predetermined level before use in the final survey report.

Depending on the survey objectives, the level and depth of the data review varies. The level and depth of the data review may be determined during the planning process and should include an examination of laboratory and method performance for the measurements and radionuclides involved. This examination includes

- evaluation of data completeness
- verification of instrument calibration
- measurement of precision using duplicates, replicates, or split samples
- measurement of bias using reference materials or spikes
- examination of blanks for contamination
- assessment of adherence to method specifications and QC limits
- evaluation of method performance in the sample matrix
- applicability and validation of analytical procedures for site-specific measurements
- assessment of external QC measurement results and QA assessments

A different level or depth of data review may be indicated by the results of this evaluation. Specific data review procedures are dependent upon the survey objectives and should be documented in the QAPP.

N.6 Data Quality Indicators

The assessment of data quality indicators presented in this section is significant to determine data usability. The principal data quality indicators are precision, bias, representativeness, comparability, and completeness (EPA 1997a). Other data quality indicators affecting the RSSI process include the selection and classification of survey units, Type I and Type II decision error rates, the variability in the radionuclide concentration measured within the survey unit, and the lower bound of the gray region (see Section 2.3.1).

Of the six principal data quality indicators, precision and bias are quantitative measures, representativeness and comparability are qualitative, completeness is a combination of both qualitative and quantitative measures, and accuracy is a combination of precision and bias. The selection and classification of survey units is qualitative, while decision error rates, variability, and the lower bound of the gray region are quantitative measures.

The major activity in determining the usability of data based on survey activities is assessing the effectiveness of measurements. Scanning and direct measurements taken during survey activities and samples collected for analysis should meet site-specific objectives based on scoping and planning decisions.

Determining the usability of analytical results begins with the review of QC measurements and qualifiers to assess the measurement result and the performance of the analytical method. If an error in the data is discovered, it is more important to evaluate the effect of the error on the data than to determine the source of the error. The documentation described in Section N.2 is reviewed as a whole for some criteria. Data are reviewed at the measurement level for other criteria.

Factors affecting the accuracy of identification and the precision and bias of quantitation of individual radionuclides, such as calibration and recoveries, should be examined radionuclide by radionuclide. Table N.1 presents a summary of the QC measurements and the data use implications.

N.6.1 Precision

Precision is a measure of agreement among replicate measurements of the same property under prescribed similar conditions. This agreement is calculated as either the range or the standard deviation. It may also be expressed as a percentage of the mean of the measurements such as relative range (for duplicates) or coefficient of variation.

Table N.1 Use of Quality Control Data

Quality Control Criterion	Effect on Identification When Criterion is Not Met	Quantitative Bias	Use
Spikes (Higher than expected result)	Potential for incorrectly deciding a survey unit does not meet the release criterion (Type II decision error)	High	Use data as upper limit
Spikes (Lower than expected result)	Potential for incorrectly deciding a survey unit does meet the release criterion[a] (Type I decision error)	Low	Use data as lower limit
Replicates (Inconsistent)	None, unless analyte found in one duplicate and not the other—then either Type I or Type II decision error	High or Low[b]	Use data as estimate—poor precision
Blanks (Contaminated)	Potential for incorrectly deciding a survey unit does not meet the release criterion (Type II decision error)	High	Check for gross contamination or instrument malfunction
Calibration (Bias)	Potential for Type I or Type II decision errors	High or Low[b]	Use data as estimate unless problem is extreme

[a] Only likely if recovery is near zero.
[b] Effect on bias determined by examination of data for each radionuclide.

For scanning and direct measurements, precision may be specified for a single person performing the measurement or as a comparison between people performing the same measurement. For laboratory analyses, precision may be specified as either intralaboratory (within a laboratory) or interlaboratory (between laboratories). Precision estimates based on a single surveyor or laboratory represent the agreement expected when the same person or laboratory uses the same method to perform multiple measurements of the same location. Precision estimates based on two or more surveyors or laboratories refer to the agreement expected when different people or laboratories perform the same measurement using the same method.

The two basic activities performed in the assessment of precision are estimating the radionuclide concentration variability from the measurement locations and estimating the measurement error attributable to the data collection process. The level for each of these performance measures

should be specified during development of DQOs. If the statistical performance objectives are not met, additional measurements should be taken or one (or more) of the performance parameters changed.

Measurement error is estimated using the results of replicate measurements, as discussed in Chapter 6 for field measurements and Chapter 7 for laboratory measurements. When collocated measurements are performed (in the field or in the laboratory) an estimate of total precision is obtained. When collocated samples are not available for laboratory analysis, a sample subdivided in the field and preserved separately can be used to assess the variability of sample handling, preservation, and storage along with the variability in the analytical process, but variability in sample acquisition is not included. When only variability in the analytical process is desired, a sample can be subdivided in the laboratory prior to analysis.

Summary statistics such as sample mean and sample variance can provide as assessment of the precision of a measurement system or component thereof for a project. These statistics may be used to estimate precision at discrete concentration levels, average estimated precision over applicable concentration ranges, or provide the basis for a continual assessment of precision for future measurements. Methods for calculating and reporting precision are provided in *EPA Guidance for Quality Assurance Project Plans* (EPA 1997a).

Table N.2 presents the minimum considerations, impacts if the considerations are not met, and corrective actions for precision.

N.6.2 Bias

Bias is the systematic or persistent distortion of a measurement process that causes errors in one direction. Bias assessments for radioanalytical measurements should be made using personnel, equipment, and spiking materials or reference materials as independent as possible from those used in the calibration of the measurement system. When possible, bias assessments should be based on certified reference materials rather than matrix spikes or water spikes so that the effect of the matrix and the chemical composition of the contamination is incorporated into the assessment. While matrix spikes include matrix effects, the addition of a small amount of liquid spike does not always reflect the chemical composition of the contamination in the sample matrix. Water spikes do not account for either matrix effects or chemical composition of the contamination. When spikes are used to assess bias, a documented spiking protocol and consistency in following that protocol are important to obtaining meaningful data quality estimates.

Table N.2 Minimum Considerations for Precision, Impact if Not Met, and Corrective Actions

Minimum Considerations for Precision	Impact When Minimum Considerations Are Not Met	Corrective Action
Confidence level as specified in DQOs. Power as specified in DQOs. Minimum detectable relative differences specified in the survey design and modified after analysis of background measurements if necessary One set of field duplicates or more as specified in the survey design. Analytical duplicates and splits as specified in the survey design. Measurement error specified.	Errors in decisions to act or not to act based on analytical data. Unacceptable level of uncertainty. Increased variability of quantitative results. Potential for incorrectly deciding a survey unit does meet the release criterion for measurements near the detection limits (Type I decision error).	For Surveying and Sampling: Add survey or sample locations based on information from available data that are known to be representative. Adjust performance objectives. For Analysis: Analysis of new duplicate samples. Review laboratory protocols to ensure comparability. Use precision measurements to determine confidence limits for the effects on the data. The investigator can use the maximum measurement results to set an upper bound on the uncertainty if there is too much variability in the analyses.

Activity levels for bias assessment measurements should cover the range of expected contaminant concentrations, although the minimum activity is usually at least five times the MDC. For many final status surveys, the expected contaminant concentration is zero or background, so the highest activity will be associated with the bias assessment measurements. The minimum and maximum concentrations allowable in bias assessment samples should be agreed on during survey planning activities to prevent accidental contamination of the environment or an environmental level radioanalytical laboratory.

For scanning and direct measurements there are a limited number of options available for performing bias assessment measurements. Perhaps the best estimate of bias for scanning and direct measurements is to collect samples from locations where scans or direct measurements were performed, analyze the samples in a laboratory, and compare the results. Problems associated with this method include the time required to obtain the results and the difficulty in

obtaining samples that are representative of the field measurement to provide comparable results. A simple method of demonstrating that analytical bias is not a significant problem for scanning or direct measurements is to use the instrument performance checks to demonstrate the lack of analytical bias. A control chart can be used to determine the variability of a specific instrument and track the instrument performance throughout the course of the survey. Field background measurements can also be plotted on a control chart to estimate bias caused by contamination of the instrument.

There are several types of bias assessment samples available for laboratory analyses as discussed in Chapter 7. Field blanks can be evaluated to estimate the potential bias caused by contamination from sample collection, preparation, shipping, and storage.

Table N.3 presents the minimum considerations, impacts if the considerations are not met, and corrective actions for bias.

Table N.3 Minimum Considerations for Bias, Impact if Not Met, and Corrective Actions

Minimum Considerations for Bias	Impact When Minimum Considerations Are Not Met	Corrective Action
Matrix spikes to assess bias of non-detects and positive sample results if specified in the survey design. Analytical spikes as specified in the survey design. Use analytical methods (routine methods whenever possible) that specify expected or required recovery ranges using spikes or other QC measures. No radionuclides of potential concern detected in the blanks.	Potential for incorrectly deciding a survey unit does meet the release criterion (Type I decision error): if spike recovery is low, it is probable that the method or analysis is biased low for that radionuclide and values of all related samples may underestimate the actual concentration. Potential for incorrectly deciding a survey unit does not meet the release criterion (Type II decision error): if spike recovery exceeds 100%, interferences may be present, and it is probable that the method or analysis is biased high. Analytical results overestimate the true concentration of the spiked radionuclide.	Consider resampling at affected locations. If recoveries are extremely low or extremely high, the investigator should consult with a radiochemist or health physicist to identify a more appropriate method for reanalysis of the samples.

N.6.3 Accuracy

Accuracy is a measure of the closeness of an individual measurement or the average of a number of measurements to the true value (EPA 1997a). Accuracy includes a combination of random error (precision) and systematic error (bias) components that result from performing measurements. Systematic and random uncertainties (or errors) are discussed in more detail in Section 6.8.1.

Accuracy is determined by analyzing a reference material of known contaminant concentration or by reanalyzing material to which a known concentration of contaminant has been added. To be accurate, data must be both precise and unbiased. Using the analogy of archery, to be accurate one's arrows must land close together and, on average, at the spot where they are aimed. That is, the arrows must all land near the bull's eye (see Figure N.1).

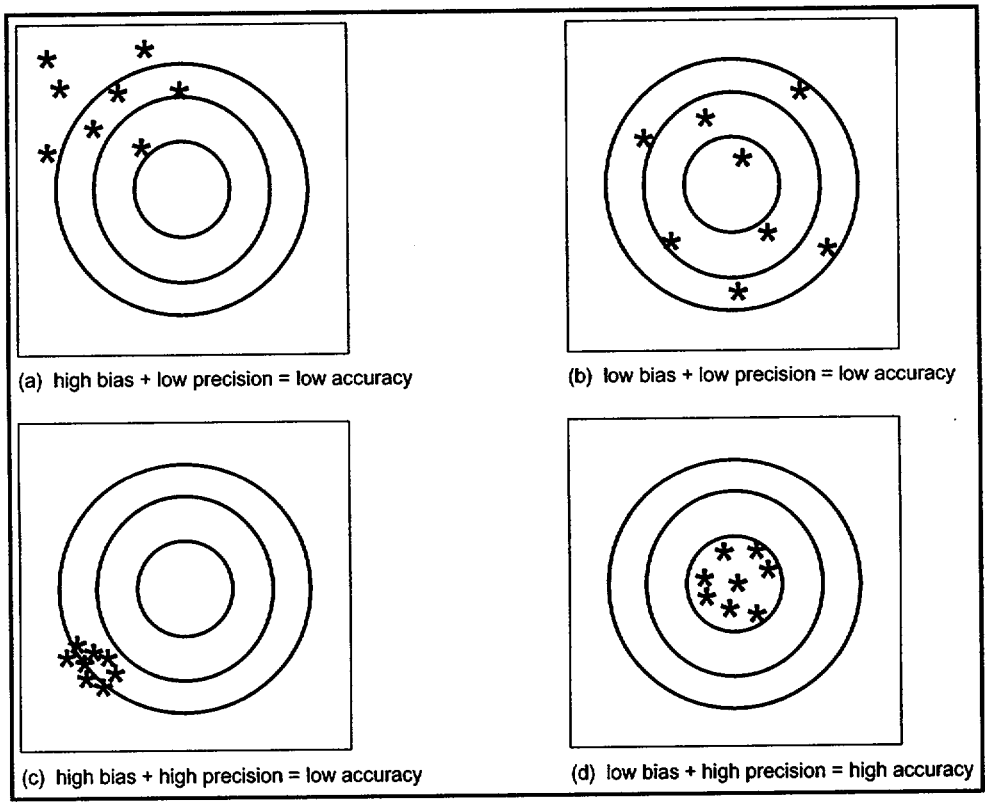

Figure N.1 Measurement Bias and Random Measurement Uncertainty

Accuracy is usually expressed either as a percent recovery or as a percent bias. Determination of accuracy always includes the effects of variability (precision); therefore, accuracy is used as a combination of bias and precision. The combination is known statistically as mean square error. Mean square error is the quantitative term for overall quality of individual measurements or estimators.

Mean square error is the sum of the variance plus the square of the bias. (The bias is squared to eliminate concern over whether the bias is positive or negative.) Frequently it is impossible to quantify all of the components of the mean square error—especially the biases—but it is important to attempt to quantify the magnitude of such potential biases, often by comparison with auxiliary data.

N.6.4 Representativeness

Representativeness is a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point or for a process condition or environmental condition. Representativeness is a qualitative term that should be evaluated to determine whether *in situ* and other measurements are made and physical samples collected in such a manner that the resulting data appropriately reflect the media and contamination measured or studied.

Representativeness of data is critical to data usability assessments. The results of the environmental radiological survey will be biased to the degree that the data do not reflect the radionuclides and concentrations present at the site. Non-representative radionuclide identification may result in false negatives. Non-representative estimates of concentrations may be higher or lower than the true concentration. With few exceptions, non-representative measurements are only resolved by additional measurements.

Representativeness is primarily a planning concern. The solution to enhancing representativeness is in the design of the survey plan. Representativeness is determined by examining the survey plan. Analytical data quality affects representativeness since data of low quality may be rejected for use.

Table N.4 presents the minimum considerations, impacts if the considerations are not met, and corrective actions for representativeness.

N.6.5 Comparability

Comparability is the qualitative term that expresses the confidence that two data sets can contribute to a common analysis and interpolation. Comparability should be carefully evaluated to establish whether two data sets can be considered equivalent in regard to the measurement of a specific variable or groups of variables.

Table N.4 Minimum Considerations for Representativeness, Impact if Not Met, and Corrective Actions

Minimum Considerations for Representativeness	Impact When Minimum Considerations Are Not Met	Corrective Action
Survey data representative of survey unit. Documented sample preparation procedures. Filtering, compositing, and sample preservation may affect representativeness. Documented analytical data as specified in the survey design.	Bias high or low in estimate of extent and quantity of contaminated material. Potential for incorrectly deciding a survey unit does meet the release criterion (Type I decision error). Inaccurate identification or estimate of concentration of a radionuclide. Remaining data may no longer sufficiently represent the site if a large portion of the data are rejected, or if all data from measurements at a specific location are rejected.	Additional surveying or sampling. Examination of effects of sample preparation procedures. Reanalysis of samples, or resurveying or resampling of the affected site areas. If the resurveying, resampling, or reanalyses cannot be performed, document in the site environmental radiological survey report what areas of the site are not represented due to poor quality of analytical data.

Comparability is not compromised provided that the survey design is unbiased, and the survey design or analytical methods are not changed over time. Comparability is a very important qualitative data indicator for analytical assessment and is a critical parameter when considering the combination of data sets from different analyses for the same radionuclides. The assessment of data quality indicators determines if analytical results being reported are equivalent to data obtained from similar analyses. Only comparable data sets can be readily combined.

The use of routine methods (as defined in Section 7.6) simplifies the determination of comparability because all laboratories use the same standardized procedures and reporting parameters. In other cases, the decision maker may have to consult with a health physicist and/or radiochemist to evaluate whether different methods are sufficiently comparable to combine data sets.

There are a number of issues that can make two data sets comparable, and the presence of each of the following items enhances their comparability (EPA 1997a).

- two data sets should contain the same set of variables of interest.
- units in which these variables were measured should be convertible to a common metric.
- similar analytic procedures and quality assurance should be used to collect data for both data sets
- time of measurements of certain characteristics (variables) should be similar for both data sets
- measuring devices used for both data sets should have approximately similar detection levels
- rules for excluding certain types of observations from both samples should be similar
- samples within data sets should be selected in a similar manner
- sampling frames from which the samples were selected should be similar
- number of observations in both data sets should be of the same order of magnitude

These characteristics vary in importance depending on the final use of the data. The closer two data sets are with regard to these characteristics, the more appropriate it will be to compare them. Large differences between characteristics may be of only minor importance depending on the decision that is to be made from the data.

Table N.5 presents the minimum considerations, impacts if they are not met, and corrective actions for comparability.

N.6.6 Completeness

Completeness is a measure of the amount of valid data obtained from the measurement system, expressed as a percentage of the number of valid measurements that should have been collected (*i.e.*, measurements that were planned to be collected).

Completeness for measurements is calculated by the following formula:

$$\%Completeness = \frac{(Number\ of\ Valid\ Measurements)\ x\ 100}{Total\ Number\ of\ Measurements\ Planned}$$

Completeness is not intended to be a measure of representativeness; that is, it does not describe how closely the measured results reflect the actual concentration or distribution of the contaminant in the media being measured. A project could produce 100% data completeness (*i.e.*, all planned measurements were actually performed and found valid), but the results may not be representative of the actual contaminant concentration.

Table N.5 Minimum Considerations for Comparability, Impact if Not Met, and Corrective Actions

Minimum Considerations for Comparability	Impact When Minimum Considerations Are Not Met	Corrective Action
Unbiased survey design or documented reasons for selecting another survey design. The analytical methods used should have common analytical parameters. Same units of measure used in reporting. Similar detection limits. Equivalent sample preparation techniques. Analytical equipment with similar efficiencies or the efficiencies should be factored into the results.	Non-additivity of survey results. Reduced confidence, power, and ability to detect differences, given the number of measurements available. Increased overall error.	For Surveying and Sampling: Statistical analysis of effects of bias. For Analytical Data: Preferentially use those data that provide the most definitive identification and quantitation of the radionuclides of potential concern. For quantitation, examine the precision and accuracy data along with the reported detection limits. Reanalysis using comparable methods.

Alternatively, there could be only 70% data completeness (30% lost or found invalid), but, due to the nature of the survey design, the results could still be representative of the target population and yield valid estimates. The degree to which lack of completeness affects the outcome of the survey is a function of many variables ranging from deficiencies in the number of measurements to failure to analyze as many replications as deemed necessary by the QAPP and DQOs. The intensity of effect due to incompleteness of data is sometimes best expressed as a qualitative measure and not just as a quantitative percentage.

Completeness can have an effect on the DQO parameters. Lack of completeness may require reconsideration of the limits for decision error rates because insufficient completeness will decrease the power of the statistical tests described in Chapter 8.

For most final status surveys, the issue of completeness only arises when the survey unit demonstrates compliance with the release criterion and less than 100% of the measurements are determined to be acceptable. The question now becomes whether the number of measurements is sufficient to support the decision to release the survey unit. This question can be answered by constructing a power curve as described in Appendix I and evaluating the results. An alternative

method is to consider that the number of measurements estimated to demonstrate compliance in Chapter 5 was increased by 20% to account for lost or rejected data and uncertainty in the calculation of the number of measurements. This means a survey with 80% completeness may still have sufficient power to support a decision to release the survey unit.

Table N.6 presents the minimum considerations, impacts if the considerations are not met, and corrective actions for completeness.

Table N.6 Minimum Considerations for Completeness, Impact if Not Met, and Corrective Actions

Minimum Considerations for Completeness	Impact When Minimum Considerations Are Not Met	Corrective Action
Percentage of measurement completeness determined during planning to meet specified performance measures.	Higher potential for incorrectly deciding a survey unit does not meet the release criterion (Type II decision error). Reduction in power. A reduction in the number of measurements reduces site coverage and may affect representativeness. Reduced ability to differentiate site levels from background. Impact of incompleteness generally decreases as the number of measurements increases.	Resurveying, resampling, or reanalysis to fill data gaps. Additional analysis of samples already in laboratory. Determine whether the missing data are crucial to the survey.

N.6.7 Selection and Classification of Survey Units

Selection and classification of survey units is a qualitative measure of the assumptions used to develop the survey plan. The level of survey effort, measurement locations (*i.e.*, random vs. systematic and density of measurements), and the integrated survey design are based on the survey unit classification. The results of the survey should be reviewed to determine whether the classification used to plan the survey is supported by the results of the survey.

If a Class 3 survey unit is found to contain areas of contamination (even if the survey unit passes the statistical tests), the survey unit may be divided into several survey units with appropriate classifications, and additional surveys planned as necessary for these new survey units.

Class 3 areas may only require additional randomly located measurements to provide sufficient power to release the new survey units. Class 2 and Class 1 areas will usually require a new survey design based on systematic measurement locations, and Class 1 areas may require remediation before a new final status survey is performed.

If a Class 2 survey unit is determined to be a Class 1 survey unit following the final status survey and remediation is not required, it may not be necessary to plan a new survey. The scan MDC should be compared to the $DCGL_{EMC}$ to determine if the measurement spacing is adequate to meet the survey objectives. If the scan MDC is too high, a new scan survey using a more sensitive measurement technique may be available. Alternatively, a new survey may be planned using a new measurement spacing or a stratified survey design may be implemented to use as much of the existing data as possible.

N.6.8 Decision Error Rates

The decision error rates developed during survey planning are related to completeness. A low level of completeness will affect the power of the statistical test. It is recommended that a power curve be constructed as described in Appendix I, and the expected decision error rates compared to the actual decision error rates to determine if the survey objectives have been accomplished.

N.6.9 Variability in Contaminant Concentration

The variability in the contaminant concentration (both in the survey unit and the reference area) is a key parameter in survey planning, and is related to the precision of the measurements. Statistical simulations show that underestimating the value of σ (the standard deviation of the survey unit measurements) can greatly increase the probability that a survey unit will fail to demonstrate compliance with the release criterion.

If a survey unit fails to demonstrate compliance and the actual σ is greater than the σ used during survey planning, there are several options available to the project manager. If the major component of variability is measurement uncertainty, a new survey can be designed using a measurement technique with higher precision or a lower MDC to reduce variability. If samples were collected as part of the survey design, it may only be necessary to reanalyze the samples using a method with higher precision rather than collect additional samples. Alternatively, the number of measurements can be increased to reduce the variability.

If the variability is due to actual variations in the contaminant concentration, there are still options available. If there is a high variability in the reference area, it may be appropriate to demonstrate the survey unit is indistinguishable from background. NUREG 1505 (NRC 1997b) provides guidance on determining whether this test is appropriate and performing the statistical tests. If the variability is caused by different contaminant distributions in different parts of the site (*i.e.*, changing soil types influences contaminant concentrations), it may be appropriate to redefine the survey unit boundaries to provide a more homogeneous set of survey units.

N.6.10 Lower Bound of the Gray Region

The lower bound of the gray region (LBGR) is used to calculate the relative shift, which in turn is used to estimate the number of measurements required to demonstrate compliance. The LBGR is initially set arbitrarily to one half the $DCGL_W$. If this initial selection is used to design the survey, there is no technical basis for the selection of this value. This becomes important because the Type II decision error rate (β) is calculated at the LBGR.

For survey units that pass the statistical tests, the value selected for the LBGR is generally not a concern. If the survey unit fails to demonstrate compliance, it may be caused by improper selection of the LBGR. Because the number of measurements estimated during survey planning is based on the relative shift (which includes both σ and the LBGR), MARSSIM recommends that a power curve be constructed as described in Appendix I. If the survey unit failed to demonstrate compliance because of a lack of statistical power, an adjustment of the LBGR may be necessary when planning subsequent surveys.

GLOSSARY

91b material: Any material identified under Section 91b of the Atomic Energy Act of 1954 (42 U.S.C. Section 2121).

A_{min}: The smallest *area of elevated activity* identified using the DQO Process that is important to identify.

action level: The numerical value that will cause the *decision maker* to choose one of the alternative actions. It may be a regulatory threshold standard (*e.g.*, Maximum Contaminant Level for drinking water), a dose- or risk-based concentration level (*e.g.*, *DCGL*), or a reference-based standard. See *investigation level.*

activity: See *radioactivity.*

ALARA (acronym for As Low As Reasonably Achievable): A basic concept of radiation protection which specifies that exposure to ionizing radiation and releases of radioactive materials should be managed to reduce collective doses as far below regulatory limits as is reasonably achievable considering economic, technological, and societal factors, among others. Reducing exposure at a site to *ALARA* strikes a balance between what is possible through additional planning and management, remediation, and the use of additional resources to achieve a lower collective dose level. A determination of *ALARA* is a site-specific analysis that is open to interpretation, because it depends on approaches or circumstances that may differ between regulatory agencies. An *ALARA* recommendation should not be interpreted as a set limit or level.
alpha (α): The specified maximum probability of a *Type I error.* In other words, the maximum probability of rejecting the *null hypothesis* when it is true. *Alpha* is also referred to as the *size of the test. Alpha* reflects the amount of evidence the *decision maker* would like to see before abandoning the *null hypothesis.*

alpha particle: A positively charged particle emitted by some radioactive materials undergoing *radioactive decay.*

alternative hypothesis (H_a): See *hypothesis.*

area: A general term referring to any portion of a *site*, up to and including the entire *site.*

area of elevated activity: An *area* over which *residual radioactivity* exceeds a specified value $DCGL_{EMC}$.

area factor (A_m): A factor used to adjust $DCGL_W$ to estimate $DCGL_{EMC}$ and the *minimum detectable concentration* for scanning surveys in *Class 1* survey units—$DCGL_{EMC} = DCGL_W \cdot A_m$. A_m is the magnitude by which the *residual radioactivity* in a small *area of elevated activity* can exceed the $DCGL_W$ while maintaining compliance with the *release criterion*. Examples of *area factors* are provided in Chapter 5 of this manual.

arithmetic mean: The average value obtained when the sum of individual values is divided by the number of values.

arithmetic standard deviation: A statistic used to quantify the variability of a set of data. It is calculated in the following manner: 1) subtracting the arithmetic mean from each data value individually, 2) squaring the differences, 3) summing the squares of the differences, 4) dividing the sum of the squared differences by the total number of data values less one, and 5) taking the square root of the quotient. The calculation process produces the Root Mean Square Deviation (RMSD).

assessment: The evaluation process used to measure the performance or effectiveness of a system and its elements. As used in MARSSIM, assessment is an all-inclusive term used to denote any of the following: audit, performance evaluation, management systems review, peer review, inspection, or surveillance.

attainment objectives: Objectives that specify the design and scope of the sampling study including the radionuclides to be tested, the cleanup standards to be attained, the measure or parameter to be compared to the cleanup standard, and the *Type I* and *Type II* error rates for the selected statistical tests.

audit (quality): A systematic and independent examination to determine whether quality activities and related results comply with planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve objectives.

background reference area: See *reference area*.

background radiation: Radiation from cosmic sources, *naturally occurring radioactive material*, including radon (except as a decay product of *source* or *special nuclear material*), and global fallout as it exists in the environment from the testing of nuclear explosive devices or from nuclear accidents like Chernobyl which contribute to *background radiation* and are not under the control of the cognizant organization. *Background radiation* does not include radiation from *source*, *byproduct*, or *special nuclear materials* regulated by the cognizant Federal or State agency. Different definitions may exist for this term. The definition provided in regulations or regulatory program being used for a site release should always be used if it differs from the definition provided here.

Becquerel (Bq): The International System (SI) unit of activity equal to one nuclear transformation (disintegration) per second. 1 *Bq* = 2.7×10^{-11} *Curies (Ci)* = 27.03 picocuries (pCi).

beta (β): The probability of a *Type II error*, *i.e.*, the probability of accepting the null hypothesis when it is false. The complement of *beta* (1-β) is referred to as the *power* of the test.

beta particle: An electron emitted from the nucleus during *radioactive decay*.

bias: The systematic or persistent distortion of a measurement process which causes errors in one direction (*i.e.*, the expected sample measurement is different from the sample's true value).

biased sample or measurement: See *judgement measurement*.

byproduct material: Any radioactive material (except *special nuclear material*) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing *special nuclear material*.

calibration: Comparison of a measurement standard, instrument, or item with a standard or instrument of higher accuracy to detect and quantify inaccuracies and to report or eliminate those inaccuracies by adjustments.

CDE (committed dose equivalent): The *dose equivalent* calculated to be received by a tissue or organ over a 50-year period after the intake into the body. It does not include contributions from radiation sources external to the body. CDE is expressed in units of Sv or rem.

CEDE (committed effective dose equivalent): The sum of the committed *dose equivalent* to various tissues in the body, each multiplied by the appropriate weighting factor (W_t). CEDE is expressed in units of Sv or rem. See *TEDE*.

chain of custody: An unbroken trail of accountability that ensures the physical security of samples, data, and records.

characterization survey: A type of *survey* that includes facility or *site* sampling, monitoring, and analysis activities to determine the extent and nature of contamination. *Characterization surveys* provide the basis for acquiring necessary technical information to develop, analyze, and select appropriate *cleanup* techniques.

Class 1 area: An *area* that is projected to require a *Class 1 final status survey*.

Class 1 survey: A type of *final status survey* that applies to *areas* with the highest potential for contamination, and meet the following criteria: (1) *impacted*; (2) potential for delivering a dose above the *release criterion*; (3) potential for small *areas of elevated activity*; and (4) insufficient evidence to support reclassification as *Class 2* or *Class 3*.

Class 2 area: An *area* that is projected to require a *Class 2 final status survey*.

Class 2 survey: A type of *final status survey* that applies to *areas* that meet the following criteria: (1) *impacted*; (2) low potential for delivering a dose above the *release criterion*; and (3) little or no potential for small *areas of elevated activity*.

Class 3 area: An *area* that is projected to require a *Class 3 final status survey*.

Class 3 survey: A type of *final status survey* that applies to *areas* that meet the following criteria: (1) *impacted*; (2) little or no potential for delivering a dose above the *release criterion*; and (3) little or no potential for small *areas of elevated activity*.

classification: The act or result of separating *areas* or *survey units* into one of three designated classes: *Class 1 area*, *Class 2 area*, or *Class 3 area*.

cleanup: Actions taken to deal with a release or threatened release of hazardous substances that could affect public health or the environment. The term is often used broadly to describe various Superfund response actions or phases of remedial responses, such as remedial investigation/ feasibility study. Cleanup is sometimes used interchangeably with the terms *remedial action*, response action, or *corrective action*.

cleanup standard: A numerical limit set by a regulatory agency as a requirement for releasing a *site* after *cleanup*. See *release criterion*.

cleanup (survey) unit: A geographical *area* of specified size and shape defined for the purpose of survey design and compliance testing.

coefficient of variation: A unitless measure that allows the comparison of dispersion across several sets of data. It is often used in environmental applications because variability (expressed as a standard deviation) is often proportional to the mean. See *relative standard deviation*.

comparability: A measure of the confidence with which one data set can be compared to another.

completeness: A measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under correct, normal conditions.

composite sample: A sample formed by collecting several samples and combining them (or selected portions of them) into a new sample which is then thoroughly mixed.

conceptual site model: A description of a site and its environs and presentation of hypotheses regarding the contaminants present, their routes of migration, and their potential impact on sensitive receptors.

confidence interval: A range of values for which there is a specified probability (*e.g.*, 80%, 90%, 95%) that this set contains the true value of an estimated parameter.

confirmatory survey: A type of *survey* that includes limited independent (third-party) measurements, sampling, and analyses to verify the findings of a *final status survey*.

consensus standard: A standard established by a group representing a cross section of a particular industry or trade, or a part thereof.

contamination: The presence of *residual radioactivity* in excess of levels which are acceptable for release of a *site* or facility for *unrestricted use*.

control chart: A graphic representation of a process, showing plotted values of some statistic gathered from that characteristic, and one or two control limits. It has two basic uses: 1) as a judgement to determine if a process was in control, and 2) as an aid in achieving and maintaining statistical control.

core sample: A soil sample taken by core drilling.

corrective action: An action taken to eliminate the causes of an existing nonconformance, deficiency, or other undesirable situation in order to prevent recurrence.

criterion: See *release criterion*.

critical group: The group of individuals reasonably expected to receive the greatest exposure to *residual radioactivity* for any applicable set of circumstances.

critical level (L_c): A fixed value of the *test statistic* corresponding to a given probability level, as determined from the sampling distribution of the *test statistic*. L_c is the level at which there is a statistical probability (with a predetermined confidence) of correctly identifying a background value as "greater than background."

critical value: The value of a statistic (t) corresponding to a given significance level as determined from its sampling distribution; e.g., if Pr ($t > t_o$) = 0.05, t_o is the critical value of t at the 5 percent level.

curie (Ci): The customary unit of radioactivity. One *curie* (Ci) is equal to 37 billion disintegrations per second (3.7×10^{10} dps = 3.7×10^{10} *Bq*), which is approximately equal to the decay rate of one gram of ^{226}Ra. Fractions of a *curie*, *e.g.* picocurie (pCi) or 10^{-12} Ci and microcurie (μCi) or 10^{-6} Ci, are levels typically encountered in *decommissioning*.

cyclotron: A device used to impart high energy to charged particles, of atomic weight one or greater, which can be used to initiate nuclear transformations upon collision with a suitable target.

D: The true, but unknown, value of the difference between the mean concentration of *residual radioactivity* in the *survey unit* and the *reference area.*

DQA (Data Quality Assessment): The scientific and statistical evaluation of data to determine if the data are of the right type, quality, and quantity to support their intended use.

DQOs (Data Quality Objectives): Qualitative and quantitative statements derived from the DQO process that clarify study technical and quality objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.

Data Quality Objectives Process: A systematic strategic planning tool based on the scientific method that identifies and defines the type, quality, and quantity of data needed to satisfy a specified use. The key elements of the process include:

- concisely defining the problem
- identifying the decision to be made
- identifying the inputs to that decision
- defining the boundaries of the study
- developing the decision rule
- specifying tolerate limits on potential decision errors
- selecting the most resource efficient data collection design

DQOs are the qualitative and quantitative outputs from the DQO process. The DQO process was developed originally by the U.S. Environmental Protection Agency, but has been adapted for use by other organizations to meet their specific planning requirement. See also *graded approach.*

data quality indicators: Measurable attributes of the attainment of the necessary quality for a particular decision. *Data quality indicators* include *precision, bias, completeness, representativeness, reproducibility, comparability*, and statistical confidence.

data usability: The process of ensuring or determining whether the quality of the data produced meets the intended use of the data.

DCGL (derived concentration guideline level): A derived, radionuclide-specific activity concentration within a *survey unit* corresponding to the *release criterion*. The *DCGL* is based on the spatial distribution of the contaminant and hence is derived differently for the *nonparametric* statistical test ($DCGL_W$) and the *Elevated Measurement Comparison* ($DCGL_{EMC}$). *DCGLs* are derived from activity/dose relationships through various *exposure pathway* scenarios.

decay: See *radioactive decay*.

decision maker: The person, team, board, or committee responsible for the final decision regarding disposition of the *survey unit*.

decision rule: A statement that describes a logical basis for choosing among alternative actions.

decommission: To remove a facility or *site* safely from service and reduce *residual radioactivity* to a level that permits release of the property and termination of the *license* and other authorization for site operation.

decommissioning: The process of removing a facility or *site* from operation, followed by *decontamination*, and license termination (or termination of authorization for operation) if appropriate. The objective of *decommissioning* is to reduce the *residual radioactivity* in structures, materials, soils, groundwater, and other media at the *site* so that the concentration of each radionuclide contaminant that contributes to *residual radioactivity* is indistinguishable from the *background radiation* concentration for that radionuclide.

decontamination: The removal of radiological contaminants from, or their neutralization on, a person, object or area to within levels established by governing regulatory agencies. *Decontamination* is sometimes used interchangeably with *remediation*, remedial action, and *cleanup*.

delta (δ): The amount that the distribution of measurements for a *survey unit* is shifted to the right of the distribution of measurements of the *reference area*.

delta (Δ): The width of the *gray region*. Δ divided by σ, the *arithmetic standard deviation* of the measurements, is the *relative shift* expressed in multiples of standard deviations. See *relative shift, gray region.*

derived concentration guideline level: See *DCGL.*

design specification process: The process of determining the sampling and analysis procedures that are needed to demonstrate that the attainment objectives are achieved.

detection limit: The net response level that can be expected to be seen with a detector with a fixed level of certainty.

detection sensitivity: The minimum level of ability to identify the presence of radiation or *radioactivity.*

direct measurement: Radioactivity measurement obtained by placing the detector near the surface or media being surveyed. An indication of the resulting radioactivity level is read out directly.

distribution coefficient (K_d): The ratio of elemental (*i.e.*, radionuclide) concentration in soil to that in water in a soil-water system at equilibrium. K_d is generally measured in terms of gram weights of soil and volumes of water (g/cm^3 or g/ml).

dose commitment: The dose that an organ or tissue would receive during a specified period of time (*e.g.*, 50 or 70 years) as a result of intake (as by ingestion or inhalation) of one or more radionuclides from a given release.

dose equivalent (dose): A quantity that expresses all radiations on a common scale for calculating the effective absorbed dose. This quantity is the product of absorbed dose (rads) multiplied by a quality factor and any other modifying factors. Dose is measured in *Sv* or *rem.*

double-blind measurement: Measurements that cannot be distinguished from routine measurements by the individual performing the measurement. See *non-blind measurement* and *single-blind measurement.*

effective probe area: The *physical probe area* corrected for the amount of the probe area covered by a protective screen.

elevated area: See *area of elevated activity.*

elevated measurement: A measurement that exceeds a specified value $DCGL_{EMC}$.

Elevated Measurement Comparison (EMC): This comparison is used in conjunction with the Wilcoxon test to determine if there are any measurements that exceed a specified value $DCGL_{EMC}$.

exposure pathway: The route by which radioactivity travels through the environment to eventually cause radiation exposure to a person or group.

exposure rate: The amount of ionization produced per unit time in air by X-rays or gamma rays. The unit of exposure rate is Roentgens/hour (R/h); for decommissioning activities the typical units are microRoentgens per hour (μR/h), *i.e.*, 10^{-6} R/h.

external radiation: Radiation from a source outside the body.

false negative decision error: The error that occurs when the null hypothesis (H_0) is not rejected when it is false. For example, the false negative decision error occurs when the decision maker concludes that the waste is hazardous when it truly is not hazardous. A statistician usually refers to a false negative error as a *Type II decision error*. The measure of the size of this error is called *beta*, and is also known as the complement of the power of a hypothesis test.

false positive decision error: A false positive decision error occurs when the null hypothesis (H_0) is rejected when it is true. Consider an example where the decision maker presumes that a certain waste is hazardous (*i.e.*, the null hypothesis or baseline condition is "the waste is hazardous"). If the decision maker concludes that there is insufficient evidence to classify the waste as hazardous when it truly is hazardous, the decision maker would make a false positive decision error. A statistician usually refers to the false positive error as a *Type I decision error*. The measure of the size of this error is called *alpha*, the level of significance, or the size of the critical region.

Field Sampling Plan: As defined for Superfund in the Code of Federal Regulations 40 CFR 300.430, a document which describes the number, type, and location of samples and the type of analyses to be performed. It is part of the *Sampling and Analysis Plan*.

final status survey: Measurements and sampling to describe the radiological conditions of a site, following completion of decontamination activities (if any) in preparation for release.

fluence rate: A fundamental parameter for assessing the level of radiation at a measurement site. In the case of *in situ* spectrometric measurements, a calibrated detector provides a measure of the *fluence rate* of primary photons at specific energies that are characteristic of a particular radionuclide.

gamma (γ) radiation: Penetrating high-energy, short-wavelength electromagnetic radiation (similar to X-rays) emitted during *radioactive decay*. Gamma rays are very penetrating and require dense materials (such as lead or steel) for shielding.

graded approach: The process of basing the level of application of managerial controls applied to an item or work according to the intended use of the results and the degree of confidence needed in the quality of the results. See *data quality objectives process*.

gray region: A range of values of the parameter of interest for a *survey unit* where the consequences of making a decision error are relatively minor. The upper bound of the gray region in MARSSIM is set equal to the $DCGL_W$, and the *lower bound of the gray region (LBGR)* is a site-specific variable.

grid: A network of parallel horizontal and vertical lines forming squares on a map that may be overlaid on a property parcel for the purpose of identification of exact locations. See *reference coordinate system*.

grid block: A square defined by two adjacent vertical and two adjacent horizontal reference grid lines.

half-life ($t_{1/2}$): The time required for one-half of the atoms of a particular radionuclide present to disintegrate.

Historical Site Assessment (HSA): A detailed investigation to collect existing information, primarily historical, on a *site* and its surroundings.

hot measurement: See *elevated measurement*.

hot spot: See *area of elevated activity*.

hypothesis: An assumption about a property or characteristic of a set of data under study. The goal of statistical inference is to decide which of two complementary hypotheses is likely to be true. The *null hypothesis* (H_0) describes what is assumed to be the true state of nature and the *alternative hypothesis* (H_a) describes the opposite situation.

impacted area: Any *area* that is not *classified* as *non-impacted.* Areas with a possibility of containing *residual radioactivity* in excess of natural background or fallout levels.

independent assessment: An assessment performed by a qualified individual, group, or organization that is not part of the organization directly performing and accountable for the work being assessed.

indistinguishable from background: The term indistinguishable from background means that the detectable concentration distribution of a radionuclide is not statistically different from the background concentration distribution of that radionuclide in the vicinity of the site or, in the case of structures, in similar materials using adequate measurement technology, survey, and statistical techniques.

infiltration rate: The rate at which a quantity of a hazardous substance moves from one environmental medium to another—*e.g.*, the rate at which a quantity of a radionuclide moves from a source into and through a volume of soil or solution.

inspection: An activity such as measuring, examining, testing, or gauging one or more characteristics of an entity and comparing the results with specified requirements in order to establish whether conformance is achieved for each characteristic.

inventory: Total residual quantity of formerly licensed radioactive material at a site.

investigation level: A derived media-specific, radionuclide-specific concentration or activity level of radioactivity that: 1) is based on the release criterion, and 2) triggers a response, such as further investigation or cleanup, if exceeded. See *action level.*

isopleth: A line drawn through points on a graph or plot at which a given quantity has the same numerical value or occurs with the same frequency.

judgment measurement: Measurements performed at locations selected using professional judgment based on unusual appearance, location relative to known contaminated areas, high potential for residual radioactivity, general supplemental information, *etc.* Judgment measurements are not included in the statistical evaluation of the survey unit data because they violate the assumption of randomly selected, independent measurements. Instead, judgment measurements are individually compared to the $DCGL_W$.

karst terrain: A kind of terrain with characteristics of relief and drainage arising from a high degree of rock solubility. The majority of karst conditions occur in limestone areas, but karst may also occur in areas of dolomite, gypsum, or salt deposits. Features associated with karst terrain may include irregular topography, abrupt ridges, sink holes, caverns, abundant springs, and disappearing streams. Well developed or well integrated drainage systems of streams and tributaries are generally not present.

klystron: An electron tube used in television, *etc.*, for converting a stream of electrons into ultra high-frequency waves that are transmitted as a pencil-like radio beam.

less-than data: Measurements that are less than the *minimum detectable concentration.*

license: A license issued under the regulations in parts 30 through 35, 39, 40, 60, 61, 70 or part 72 of 10 CFR Chapter I.

licensee: The holder of a *license.*

license termination: Discontinuation of a *license*, the eventual conclusion to *decommissioning.*

lower bound of the gray region (LBGR): The minimum value of the gray region. The width of the *gray region* (*DCGL-LBGR*) is also referred to as the shift, Δ.

lower limit of detection (L_D): The smallest amount of radiation or radioactivity that statistically yields a net result above the method background. The critical detection level, L_C, is the lower bound of the 95% detection interval defined for L_D and is the level at which there is a 5% chance of calling a background value "greater than background." This value should be used when actually counting samples or making direct radiation measurements. Any response above this level should be considered as above background; *i.e.*, a net positive result. This will ensure 95% detection capability for L_D. A 95% confidence interval should be calculated for all responses greater than L_C.

m: The number of measurements from the reference area used to conduct a statistical test.

magnetron: A vacuum tube in which the flow of ions from the heated cathode to the anode is controlled by a magnetic field externally applied and perpendicular to the electric field by which they are propelled. Magnetrons are used to produce very short radio waves.

measurement: For the purpose of MARSSIM, it is used interchangeably to mean: 1) the act of using a detector to determine the level or quantity of radioactivity on a surface or in a sample of material removed from a media being evaluated, or 2) the quantity obtained by the act of measuring.

micrometeorology: The study of weather conditions in a local or very small area, such as immediately around a tree or building, that can affect meteorological conditions.

minimum detectable concentration (MDC): The minimum detectable concentration (MDC) is the *a priori* activity level that a specific instrument and technique can be expected to detect 95% of the time. When stating the detection capability of an instrument, this value should be used. The *MDC* is the detection limit, L_D, multiplied by an appropriate conversion factor to give units of activity.

minimum detectable count rate (MDCR): The minimum detectable count rate (MDCR) is the *a priori* count rate that a specific instrument and technique can be expected to detect.

missing or unusable data: Data (measurements) that are mislabeled, lost, or do not meet quality control standards. *Less-than data* are not considered to be missing or unusable data. See *R*.

munitions: Military supplies, especially weapons and ammunition.

N: $N = m + n$, is the total number of measurements required from the reference area and a *survey unit*. See *m* and *n*.

n: Number of measurements from a survey unit used to conduct a statistical test.

n_f: The number of samples that should be collected in an *area* to assure that the required number of measurements from that area for conducting statistical tests is obtained. $n_f = n/(1-R)$.

NARM: Naturally occurring or accelerator-produced radioactive material, such as radium, and not classified as *source material*.

naturally occurring radionuclides: Radionuclides and their associated progeny produced during the formation of the earth or by interactions of terrestrial matter with cosmic rays.

non-blind measurement: Non-blind measurements are measurements that have a concentration and origin that are known to the individual performing the measurement. See *single-blind measurement* and *double-blind measurement*.

nonconformance: A deficiency in characteristic, documentation, or procedure that renders the quality of an item or activity unacceptable or indeterminate; nonfulfillment of a specified requirements.

non-impacted area: Areas where there is no reasonable possibility (extremely low probability) of residual contamination. Non-impacted areas are typically located off-site and may be used as background *reference areas*.

nonparametric test: A test based on relatively few assumptions about the exact form of the underlying probability distributions of the measurements. As a consequence, nonparametric tests are generally valid for a fairly broad class of distributions. The *Wilcoxon Rank Sum test* and the *Sign test* are examples of nonparametric tests.

normal (gaussian) distribution: A family of bell shaped distributions described by the mean and variance.

organization: a company, corporation, firm, government unit, enterprise, facility, or institution, or part thereof, whether incorporated or not, public or private, that has its own functions and administration.

outlier: Measurements that are unusually large or small relative to the rest and therefore are suspected of misrepresenting the population from which they were collected.

p: The probability that a random measurement from the *survey unit* is less than Δ.

p': The probability that the sum of two independent random measurements from the *survey unit* is less than 2Δ.

P_r: The probability that a measurement performed at a random location in the *survey unit* is greater than a measurement performed at a random location in the *reference area*.

peer review: A documented critical review of work generally beyond the state of the art or characterized by the existence of potential uncertainty. The peer review is conducted by qualified individuals (or organization) who are independent of those who performed the work, but are collectively equivalent in technical expertise (*i.e.*, peers) to those who performed the original work. The peer review is conducted to ensure that activities are technically adequate, competently performed, properly documented, and satisfy established technical and quality requirements. The peer review is an in-depth assessment of the assumptions, calculations, extrapolations, alternate interpretations, methodology, acceptance criteria, and conclusions pertaining to specific work and of the documentation that supports them. Peer reviews provide an evaluation of a subject where quantitative methods of analysis or measures of success are unavailable or undefined, such as in research and development.

performance evaluation: A type of audit in which the quantitative data generated in a measurement system are obtained independently and compared with routinely obtained data to evaluate the proficiency of an analyst or laboratory.

physical probe area: The physical surface area assessed by a detector. The physical probe area is used to make probe area corrections in the activity calculations.

Pitman efficiency: A measure of performance for statistical tests. It is equal to the reciprocal of the ratio of the sample sizes required by each of two tests to achieve the same power, as these sample sizes become large.

power (1-β): The probability of rejecting the *null hypothesis* when it is false. The power is equal to one minus the *Type II* error rate, *i.e.* (1-β).

precision: A measure of mutual agreement among individual measurements of the same property, usually under prescribed similar conditions, expressed generally in terms of the *standard deviation*.

process: A combination of people, machine and equipment, methods, and the environment in which they operate to produce a given product or service.

professional judgement: An expression of opinion, based on technical knowledge and professional experience, assumptions, algorithms, and definitions, as stated by an expert in response to technical problems.

qualified data: Any data that have been modified or adjusted as part of statistical or mathematical evaluation, data *validation*, or data *verification* operations.

quality: The totality of features and characteristics of a product or service that bear on its ability to meet the stated or implied needs and expectations of the user.

quality assurance (QA): An integrated system of management activities involving planning, implementation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected by the customer.

Quality Assurance Project Plan (QAPP): A formal document describing in comprehensive detail the necessary *QA*, *QC*, and other technical activities that must be implemented to ensure that the results of the work performed will satisfy the stated performance criteria. As defined for Superfund in the Code of Federal Regulations 40 CFR 300.430, the Quality Assurance Project Plan describes policy, organization, and functional activities and the Data Quality Objectives and measures necessary to achieve adequate data for use in selecting the appropriate remedy. The

QAPP is a plan that provides a process for obtaining data of sufficient quality and quantity to satisfy data needs. It is a part of the *Sampling and Analysis Plan.*

quality control (QC): The overall system of technical activities that measure the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the customer, operational techniques and activities that are used to fulfill requirements for *quality.*

quality indicators: Measurable attributes of the attainment of the necessary quality for a particular environmental decision. Indicators of quality include precision, bias, completeness, representativeness, reproducibility, comparability, and statistical confidence.

Quality Management Plan (QMP): A formal document that describes the quality system in terms of the organizational structure, functional responsibilities of management and staff, lines of authority, and required interfaces for those planning, implementing, and assessing all activities conducted.

quality system: A structured and documented management system describing the policies, objectives, principles, organizational authority, responsibilities, accountability, and implementation plan of an organization for ensuring quality in its work processes, products (items), and services. The quality system provides the framework for planning, implementing, and assessing work performed by the organization and for carrying out required QA and QC.

R: The rate of missing or unusable measurements expected to occur for samples collected in *reference areas* or *survey units.* See *missing or unusable data.* See n_f. (Not to be confused with the symbol for the radiation exposure unit Roentgen.)

R_A: The acceptable level of risk associated with not detecting an *area of elevated activity* of area A_{min}.

radiation survey: Measurements of radiation levels associated with a *site* together with appropriate documentation and data evaluation.

radioactive decay: The spontaneous transformation of an unstable atom into one or more different nuclides accompanied by either the emission of energy and/or particles from the nucleus, nuclear capture or ejection of orbital electrons, or fission. Unstable atoms decay into a more stable state, eventually reaching a form that does not decay further or has a very long *half-life.*

radioactivity: The mean number of nuclear transformations occurring in a given quantity of radioactive material per unit time. The International System (SI) unit of radioactivity is the *Becquerel (Bq)*. The customary unit is the *Curie (Ci)*.

radiological survey: Measurements of radiation levels and radioactivity associated with a *site* together with appropriate documentation and data evaluation.

radioluminescence: Light produced by the absorption of energy from ionizing radiation.

radionuclide: An unstable nuclide that undergoes *radioactive decay*.

random error: The deviation of an observed value from the true value is called the error of observation. If the error of observation behaves like a random variable (*i.e.*, its value occurs as though chosen at random from a probability distribution of such errors) it is called a *random error*. See *systematic error*.

readily removable: A qualitative statement of the extent to which a radionuclide can be removed from a surface or medium using non-destructive, common, housekeeping techniques (*e.g.*, washing with moderate amounts of detergent and water) that do not generate large volumes of radioactive waste requiring subsequent disposal or produce chemical wastes that are expected to adversely affect public health or the environment.

reference area: Geographical *area* from which representative reference measurements are performed for comparison with measurements performed in specific *survey units* at remediation site. A site radiological *reference area* (background area) is defined as an area that has similar physical, chemical, radiological, and biological characteristics as the site area being remediated, but which has not been contaminated by site activities. The distribution and concentration of *background radiation* in the *reference area* should be the same as that which would be expected on the *site* if that *site* had never been contaminated. More than one *reference area* may be necessary for valid comparisons if a *site* exhibits considerable physical, chemical, radiological, or biological variability.

reference coordinate system: A *grid* of intersecting lines referenced to a fixed site location or benchmark. Typically the lines are arranged in a perpendicular pattern dividing the survey location into squares or blocks of equal areas. Other patterns include three-dimensional and polar coordinate systems.

reference region: The geographical region from which *reference areas* will be selected for comparison with *survey units*.

regulation: A rule, law, order, or direction from federal or state governments regulating action or conduct. Regulations concerning radioisotopes in the environment in the United States are shared by the Environmental Protection Agency (EPA), the U.S. Nuclear Regulatory Commission (NRC), the U.S. Department of Energy (DOE), and many State governments. Federal regulations and certain directives issued by the U.S. Department of Defense(DOD) are enforced within the DOD.

relative shift (Δ/σ): Δ divided by σ, the *standard deviation* of the measurements. See *delta*.

relative standard deviation: See *coefficient of variation*.

release criterion: A regulatory limit expressed in terms of dose or risk.

rem (radiation equivalent man): The conventional unit of *dose equivalent*. The corresponding International System (SI) unit is the *Sievert (Sv)*: 1 Sv = 100 rem.

remedial action: Those actions that are consistent with a permanent remedy taken instead of, or in addition to, removal action in the event of a release or threatened release of a hazardous substance into the environment, to prevent or minimize the release of hazardous substances so that they do not migrate to cause substantial danger to present or future public health or welfare or the environment. See *remedy*.

remediation: Cleanup or other methods used to remove or contain a toxic spill or hazardous materials from a Superfund site.

remediation control survey: A type of survey that includes monitoring the progress of remedial action by real time measurement of areas being decontaminated to determine whether or not efforts are effective and to guide further *decontamination* activities.

remedy: See *remedial action*.

removable activity: Surface activity that is *readily removable* by wiping the surface with moderate pressure and can be assessed with standard radiation detectors. It is usually expressed in units of dpm/100 cm^2.

removal: The cleanup or removal of released hazardous substances, or pollutants or contaminants which may present an imminent and substantial danger; such actions as may be necessary taken in the event of the threat of release of hazardous substances into the environment; such actions as may be necessary to monitor, assess, and evaluate the threat of release of hazardous substances; the removal and disposal of material, or the taking of other such actions as may be necessary to prevent, minimize or mitigate damage to the public health or welfare or the environment.

replicate: A repeated analysis of the same sample or repeated measurement at the same location.

representative measurement: A measurement that is selected using a procedure in such a way that it, in combination with other representative measurements, will give an accurate representation of the phenomenon being studied.

representativeness: A measure of the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition.

reproducibility: The precision, usually expressed as a standard deviation, that measures the variability among the results of measurement of the same sample at different laboratories.

residual radioactivity: Radioactivity in structures, materials, soils, groundwater, and other media at a site resulting from activities under the cognizant organization's control. This includes radioactivity from all sources used by the cognizant organization, but excludes background radioactivity as specified by the applicable regulation or standard. It also includes radioactive materials remaining at the site as a result of routine or accidental releases of radioactive material at the site and previous burials at the site, even if those burials were made in accordance with the provisions of 10 CFR Part 20.

restoration: Actions to return a remediated area to a usable state following decontamination.

restricted use: A designation following *remediation* requiring radiological controls.

robust: A statistical test or method that is approximately valid under a wide range of conditions.

run chart: A chart used to visually represent data. Run charts are used to monitor a process to see whether or not the long range average is changing. Run charts are points plotted on a graph in the order in which they become available, such as parameters plotted versus time.

s: The *arithmetic standard deviation* of the mean.

S+: The *test statistic* used for the *Sign test.*

sample: (As used in MARSSIM) A part or selection from a medium located in a *survey unit* or *reference area* that represents the quality or quantity of a given parameter or nature of the whole area or unit; a portion serving as a specimen.

sample: (As used in statistics) A set of individual samples or measurements drawn from a population whose properties are studied to gain information about the entire population.

Sampling and Analysis Plan (SAP): As defined for Superfund in the Code of Federal Regulations 40 CFR 300.430, a plan that provide a process for obtaining data of sufficient quality and quantity to satisfy data needs. The sampling and analysis plans consists of two parts: 1) the *Field Sampling Plan*, which describes the number, type, and location of samples and the type of analyses; and 2) the *Quality Assurance Project Plan*, which describes policy, organization, functional activities, the Data Quality Objectives, and measures necessary to achieve adequate data for use in selecting the appropriate remedy.

scanning: An evaluation technique performed by moving a detection device over a surface at a specified speed and distance above the surface to detect radiation.

scoping survey: A type of *survey* that is conducted to identify: 1) radionuclide contaminants, 2) relative radionuclide ratios, and 3) general levels and extent of contamination.

self-assessment: Assessments of work conducted by individuals, groups, or organizations directly responsible for overseeing and/or performing the work.

shape parameter (S): For an elliptical area of elevated activity, the ratio of the semi-minor axis length to the semi-major axis length. For a circle, the shape parameter is one. A small shape parameter corresponds to a flat ellipse.

shift: See *delta (Δ)*.

Sievert (Sv): The special name for the International System (SI) unit of *dose equivalent*. 1 Sv = 100 *rem* = 1 Joule per kilogram.

Sign test: A *nonparametric* statistical test used to demonstrate compliance with the release criterion when the radionuclide of interest is not present in background and the distribution of data is not symmetric. See also *Wilcoxon Rank Sum test*.

single-blind measurement: A measurement that can be distinguished from routine measurements but are of unknown concentration. See *non-blind measurement* and *double-blind measurement*.

site: Any installation, facility, or discrete, physically separate parcel of land, or any building or structure or portion thereof, that is being considered for survey and investigation.

site reconnaissance: A visit to the *site* to gather sufficient information to support a site decision regarding the need for further action, or to verify existing site data. Site reconnaissance is not a study of the full extent of contamination at a facility or site, or a risk assessment.

size (of a test): See *alpha*.

soil: The top layer of the earth's surface, consisting of rock and mineral particles mixed with organic matter. A particular kind of earth or ground—*e.g.*, sandy soil.

soil activity (soil concentration): The level of radioactivity present in soil and expressed in units of activity per soil mass (typically Bq/kg or pCi/g).

source material: Uranium and/or Thorium other than that classified as *special nuclear material*.

source term: All residual radioactivity remaining at the *site*, including material released during normal operations, inadvertent releases, or accidents, and that which may have been buried at the site in accordance with 10 CFR Part 20.

special nuclear material: Plutonium, ^{233}U, and Uranium enriched in ^{235}U; material capable of undergoing a fission reaction.

split: A sample that has been homogenized and divided into two or more aliquots for subsequent analysis.

standard normal distribution: A *normal (Gaussian) distribution* with mean zero and variance one.

standard operating procedure (SOP): A written document that details the method for an operation, analysis, or action with thoroughly prescribed techniques and steps, and that is officially approved as the method for performing certain routine or repetitive tasks.

statistical control: The condition describing a process from which all special causes have been removed, evidenced on control chart by the absence of points beyond the control limits and by the absence of non-random patterns or trends within the control limits. A special cause is a source of variation that is intermittent, unpredictable, or unstable.

stratification: The act or result of separating an area into two or more sub-areas so as each sub-area has relatively homogeneous characteristics such as contamination level, topology, surface soil type, vegetation cover, *etc.*

subsurface soil sample: A soil sample that reflects the modeling assumptions used to develop the *DCGL* for subsurface soil activity. An example would be soil taken deeper than 15 cm below the soil surface to support surveys performed to demonstrate compliance with 40 CFR 192.

surface contamination: *Residual radioactivity* found on building or equipment surfaces and expressed in units of activity per surface area (Bq/m^2 or $dpm/100\ cm^2$).

surface soil sample: A soil sample that reflects the modeling assumptions used to develop the *DCGL* for surface soil activity. An example would be soil taken from the first 15 cm of surface soil to support surveys performed to demonstrate compliance with 40 CFR 192.

surveillance (quality): Continual or frequent monitoring and verification of the status of an entity and the analysis of records to ensure that specified requirements are being fulfilled.

survey: A systematic evaluation and documentation of radiological measurements with a correctly calibrated instrument or instruments that meet the sensitivity required by the objective of the evaluation.

survey plan: A plan for determining the radiological characteristics of a *site*.

survey unit: A geographical area consisting of structures or land areas of specified size and shape at a remediated site for which a separate decision will be made whether the unit attains the site-specific reference-based cleanup standard for the designated pollution parameter. *Survey units* are generally formed by grouping contiguous site areas with a similar use history and the same classification of contamination potential. Survey units are established to facilitate the survey process and the statistical analysis of survey data.

systematic error: An error of observation based on system faults which are biased in one or more ways, *e.g.*, tending to be on one side of the true value more than the other.

T+: The *test statistic* for the *Wilcoxon Signed Rank test*.

tandem testing: Two or more statistical tests conducted using the same data set.

technical review: A documented critical review of work that has been performed within the state of the art. The review is accomplished by one or more qualified reviewers who are independent of those who performed the work, but are collectively equivalent in technical expertise to those who performed the original work. The review is an in-depth analysis and evaluation of documents, activities, material, data, or items that require technical verification or validation for applicability, correctness, adequacy, completeness, and assurance that established requirements are satisfied.

technical systems audit (TSA): A thorough, systematic, on-site, qualitative audit of facilities, equipment, personnel, training, procedures, recordkeeping, data validation, data management, and reporting aspects of a system.

TEDE (total effective dose equivalent): The sum of the effective dose equivalent (for external exposure) and the committed effective dose equivalent (for internal exposure). TEDE is expressed in units of Sv or rem. See *CEDE*.

test statistic: A function of the measurements (or their ranks) that has a known distribution if the *null hypothesis* is true. This is compared to the *critical level* to determine if the *null hypothesis* should be accepted or rejected. See $S+$, $T+$, and W_r.

tied measurements: Two or more measurements that have the same value.

traceability: The ability to trace the history, application, or location of an entity by means of recorded identifications. In a calibration sense, traceability relates measuring equipment to national or international standards, primary standards, basic physical constants or properties, or reference materials. In a data collection sense, it relates calculations and data generated throughput the project back to the requirements for quality for the project.

triangular sampling grid: A grid of sampling locations that is arranged in a triangular pattern. See *grid*.

two-sample t test: A parametric statistical test used in place of the *Wilcoxon Rank Sum (WRS) test* if the *reference area* and *survey unit* measurements are known to be *normally (Gaussian) distributed* and there are no *less-than measurements* in either data set.

Type I decision error: A decision error that occurs when the *null hypothesis* is rejected when it is true. The probability of making a *Type I decision error* is called *alpha* (α).

Type II decision error: A decision error that occurs when the *null hypothesis* is accepted when it is false. The probability of making a *Type II decision error* is called *beta* (β).

unity rule (mixture rule): A rule applied when more than one radionuclide is present at a concentration that is distinguishable from background and where a single concentration comparison does not apply. In this case, the mixture of radionuclides is compared against default concentrations by applying the unity rule. This is accomplished by determining: 1) the ratio between the concentration of each radionuclide in the mixture, and 2) the concentration for that radionuclide in an appropriate listing of default values. The sum of the ratios for all radionuclides in the mixture should not exceed 1.

unrestricted area: Any *area* where access is not controlled by a *licensee* for purposes of protection of individuals from exposure to radiation and radioactive materials—including areas used for residential purposes.

unrestricted release: Release of a *site* from regulatory control without requirements for future radiological restrictions. Also known as unrestricted use.

validation: Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled. In design and development, validation concerns the process of examining a product or result to determine conformance to user needs.

verification: Confirmation by examination and provision of objective evidence that the specified requirements have been fulfilled. In design and development, verification concerns the process of examining a result of given activity to determine conformance to the stated requirements for that activity.

W_r: The sum of the ranks of the adjusted measurements from the reference area, used as the *test statistic* for the *Wilcoxon Rank Sum test.*

W_s: The sum of the ranks of the measurements from the survey unit, used with the *Wilcoxon Rank Sum test.*

weighting factor (W_t): The fraction of the overall health risk, resulting from uniform, whole-body radiation, attributable to specific tissue. The dose equivalent to tissue is multiplied by the appropriate weighting factor to obtain the effective dose equivalent to the tissue.

Wilcoxon Rank Sum (WRS) test: A *nonparametric* statistical test used to determine compliance with the *release criterion* when the radionuclide of concern is present in background. See also *Sign test.*

working level: A special unit of radon exposure defined as any combination of short-lived radon daughters in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. This value is approximately equal to the alpha energy released from the decay of progeny in equilibrium with 100 pCi of ^{222}Ra.

$Z_{1-\Phi}$: The value from the standard normal distribution that cuts off 100 Φ % of the upper tail of the standard normal distribution. See *standard normal distribution.*

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11. ABSTRACT *(200 words or less)*

The MARSSIM provides information on planning, conducting, evaluating, and documenting building and surface soil final status radiological surveys for demonstrating compliance with dose or risk-based regulations or standards. The MARSSIM is a multi-agency consensus document that was developed collaboratively by four Federal agencies having authority and control over radioactive materials: Department of Defense (DOD), Department of Energy (DOE), Environmental Protection Agency (EPA), and Nuclear Regulatory Commission (NRC). The MARSSIM's objective is to describe a consistent approach for building and surface soil final status surveys to meet established dose or risk-based release criteria, while at the same time encouraging an effective use of resources.

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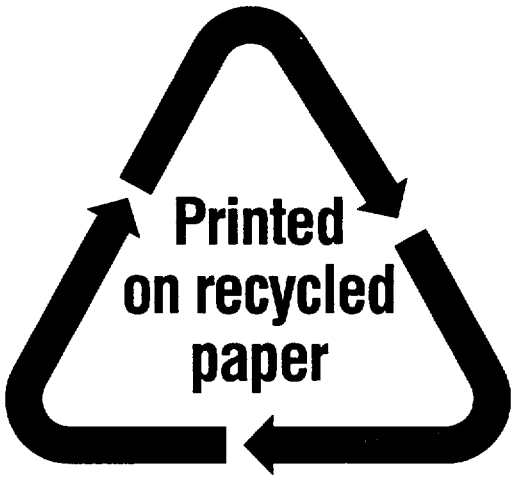

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